ACOUSTIC EMISSION MONITORING SYSTEM

FOR

WELDING THICK-WALLED VESSELS

FINAL REPORT

by

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MICROMEDIA

14 pp

Work on this project was conducted under the auspices of the
Canada Centre for Mineral and Energy Technology
Energy, Mines and Resources, Canada

DSS FILE NUMBER : 17SQ.23440-1-9038
DSS CONTRACT SERIAL NUMBER: 1SQ81-00067
CANMET SCIENTIFIC AUTHORITY: Mr. Victor Caron

March 1985

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0. OVERVIEW

This project was undertaken to develop a self-contained intelligent welding monitoring station for process and quality control with advanced signal processing techniques and pattern recognition capabilities. The following items were produced ---

* A prototype stand alone data collection hardware system with high speed data digitization, 2 or 4 channel time differential measurement, high speed interface to an LSI-11 micro computer.

* An interactive data acquisition software package with real time AE emission source location and on-line digital signal data logging capability

* A working collection of waveform parameters (features) to be used with Tektrend's advanced NDE signal analysis package, "SCANS", to classify different types of AE signal during welding.

The project comprised a series of tasks falling into three phases:

The first phase included preliminary data acquisition using laboratory specimens and data analysis to establish feasibility and design criteria for the next two phases.

The second phase involved design and construction of the prototype hardware unit, identification and development of better features to use with AE signal classification using Tektrend's "SCANS" advanced NDE signal analysis package.

The third phase includes the development of the interactive data acquisition software package and laboratory demonstration in the CANMET welding shops.

1. PHASE I : PRELIMINARY EXPERIMENTS

These preliminary experiments were carried out using laboratory specimens. The welding was done at the Welding Institute of Canada. Three types of weld defects, namely, lack of fusion, center line and crater cracks, were intended to be simulated on two thick mild steel block specimens with vee-grooves. Each weldment was sectioned later for verification of the intended type of defect. However, at the end of the experiments, only the first two kinds of the defects were produced successfully.

Over 600 AE signals were digitally captured during these experiments and they were processed and analyzed by the Tektrend SCANS package using a total of 30 waveform parameters available at that time. Three different classifiers --- Linear Discriminant Function, K-nearest Neighbor, and Minimum Distance Classifiers, were used in the study.

1.1 Results of The Preliminary Welding Experiments

As a result of these preliminary welding experiments, information useful for hardware and software development of the next two phases of the project was obtained.

The AE characteristics associated with the weld defects during and after the welding process were carefully monitored. Information such as, event emission rate, signal amplitude, signal conditioning requirements, etc., were recorded and used by the hardware design team at Tektrend as design constraints for the prototype unit.

Signals gathered during these test were submitted to the SCANS package for analysis using the 30 existing features at that time comprising features from both time and frequency domains. Time domain features mainly comprised of pulse-related information, such as pulse width, rise time, fall time. Frequency domain features consisted of partial power distribution and maximum response frequency and number of peaks. Finally, some general features, such as mean, root mean square, and higher order moment measurements, make up the total number of features used.

By optimizing the performance of signal classification under the SCANS package, reasonably high recognition rates, in the 90% region, were obtained from all three classifiers when applied to distinguish AE signals initiated from lack of fusion and centre line cracking defects from normal welding operating background signals. This confirmed the applicability of advanced signal processing methods in identifying welding defects.

From this optimization process, different subsets of the 30 available features were selected by the three classifiers to produce the best recognition rates. These selected features were analyzed carefully and the following were observed:

* None of the classifiers selected any of the feature related to the general properties of the signal.
* Information on the biggest pulse in the time domain was always selected. Pulse width and fall time were selected in all three classifiers.
* Partial power distribution was selected in two out the three classifiers being tested.
* Maximum frequency response was selected in all three classifiers.

These findings were passed on to the Tektrend software development team as a foundation for development of a better set of features to be used in phase three.

2. PHASE II : DEVELOPMENT OF THE PROTOTYPE

After analyzing the information gathered from the preliminary experiment and guided by the requirement for advanced digital signal processing, the prototype unit was conceptualized and designed in a top down fashion. This prototype unit has been code named "SLAM" for Signal Location and Acquisition Module.

2.1 The SLAM Approach

The SLAM unit is composed of the following

- Tekbus-Host Interface (THI)
- Peripheral Controller (PRCT)
- Signal Digitization Subsystem (SDS)
- Analog Conditioning Subsystem (ACS)
- Delta T Subsystem (DTS)

A bus approach was chose to simplify the design and guarantee upward compatibility for future expansion and modification. A proprietary instrument bus called "TEKBUS" was designed at the beginning and all the other systems and subsystem were then designed around this bus structure. The peripheral controller (PRCT) regulates all communication among different devices such as digitizer, delta t subsystem, analog subsystem within a physical housing and several PRCTs can be attached to the TEKBUS in a daisy chain fashion. And the TEKBUS was controlled by the Tekbus-Host Interface (THI) which communicates to the LSI-11 micro computer. Both program data tranfer and direct memory access are supported.

For the required SLAM prototype unit, a stand alone box composed of the PRCT, SDS, 4 ACS and 1 DTS was needed in addition to the THI interface. Each of these subsystems was developed independent of each other and integrated into the SLAM at the final stage.

2.2 Signal Digitization Subsystem

As observed in the preliminary experiments, AE signals emitted during and after the welding process arrived asychronously and, at times, at a rapid rate. In order to increase the chance of capturing more valid AE signals, a dual auto swapping circular data buffer was incorporated into the design. While one signal is being digitized, the other can be transferred to the computer system for analysis.

From the results of analysis of the data gathered during the preliminary experiments, information of the biggest pulse was important in distinguishing AE signals from weld defects from the background signals. This finding is also supported by conventional AE analysis. For such reasons, a flexible pretriggering circuit was included in the design to allow preservation of the leading portion of the AE signal which is usually where the biggest pulse will be observed as suggested by experience.

Because of most of the frequency domain features had be selected to produce the best recognition result, a better frequency resolution of the signal will certainly improve the signal classification performance. In doing so, a bigger data buffer size (2048 data points) was used because the frequency resolution increases linearly with the number of data points in the time domains. Guided by Tektrend's past experience in signal processing, a sampling rate of 5 MHz was chosen to be used in the digitization circuit to guarantee a full band width of 2 MHz in the frequency domain.

Also because of the asychronization and rapid emission rate of the AE signal, it is better to transfer the data to the computer system as fast as possible and direct memory access between the digitizer data buffer and the computer main memory was implemented subsequently.

The signal digitization subsystem also provides a multiplexer to allow the user to select any one of the four analog channel to be monitored for digitization.

2.3 Analog Conditioning Subsystem

In view of the dynamic characteristics of the AE signal, a versatile multipurpose analog signal conditioning module was required.

Because of the low signal amplitude output (~ 1 mV) from AE transducers, an overall system gain as high as 80 to 100 db is required to bring the AE signal to a level suitable for digitization and processing. Most signals will be pre-amplified before transmitting over a lengthy signal path to the main signal condition unit in order to maintain good signal quality. Common signal preampifiers are available in 40 to 60 db range. As a result the analog condition subsystem was designed with a two stage main amplifier providing a total gain of 40 db in 1 db steps.

In order to use the system in an operational environment, it is important to provide an effective means to filter out unwanted noise signals while maintaining a balanced match with the transducer used. For most resonant type transducer, it is recommended to operate with a band pass filtration with a center frequency conincident with its resonant frequency. With this in mind, the analog conditioning subsystem was designed with a programmable band pass filtration circuit which allows the user to select corner frequencies to match most of the commercial available transducers (from 50 KHz to 1.5 MHz).

From the working experience acquired during the preliminary welding experiments, it had been observed the AE signal emitted during the welding process might be burried in the background noise and sometimes the background noise floated high and generated false triggers to the system. In view of this, a dual mode trigger circuit was designed to allow the user to select between fixed level trigger and floating level trigger which floats along with the r.m.s. level of the signal. The floating threshold will not trigger on slow rising signal such as noise level changes; however, it will trigger on fast rising pulses such as those observed from valid AE signals. For either mode of trigger circuit, a 128 step quantized threshold level is available to the user.

As mentioned previously, it is believed the frequency content of the signal contains much useful information for signal classification. It is important to preserve the fidelity of the signal as much as possible. The design and development of this analog conditioning subsystem devoted a substantial amount of time and effort to guarantee this.

2.4 Delta T Subsystem

The delta T subsystem is dedicated to measure time differentials among the tiggered AE events and subsequently locates the source of the emission.

This circuit provides 4 16-bit independent counters all operating in a common clock frequency and each counter serves a dedicated analog channel. On reception of a reset command, all 4 counter will be reset to count 0. The arrival of the first hit event will start all four counters counting upward and each counter will stop counting when its corresponding trigger signal arrives. In other words, the first hit channel counter will always assume a value of zero.

For planar source location, an interrupt signal will be generated as soon as the fourth trigger signal is sensed, while the linear source location mode will wait for the second trigger signal.

Because the variation of sound speed in different material, a programmable clock frequency is provided to set the counting frequency from 62500 Hz in binary increments of 8 steps to 8 MHz. For a sound speed of 5000 meters per second, this translates the source location resolution into 80 mm at 62500 Hz and down to 0.625 mm at 8 MHz.

2.5 Tekbus-Host Interface and Peripheral Controller

The THI and PRCT can be considered as the master and slave controllers among different devices connected to the SLAM system. The PRCT controls devices local to the SLAM box and the THI controls one or more PRCT on the TEKBUS. All local devices talk to the PRCT and the PRCT passes the message to the THI in its turn and the message will finally be sent to the computer. It is a hierarchical structure approach and allows maxiumum flexibility and expandability.

2.6 In Search of a Better Set of Features

In conjunction with the hardware development, an equal amount of effort has been spent searching for and developing new algorithms to extract better features for use with AE signal classification during welding thick-walled vessels. Besides those features used in the preliminary analysis, two new feature domains were added, namely, auto-correlation and cepstrum domains. At the same time, the features from general properties were dropped.

Features from the auto-correlation domain are believed to be capable of bringing out structures and periodicity of a signal. From a mathematical point of view, a random signal's auto-correlogram will also be random, while the auto-correlogram from a signal with finite period will also have the same period. Local adjacent data point dependence can also be identified through inspection of the auto-correlogram. The AE pulse can be considered in an analogous way. Based on these reasons, the auto-correlation domain was added to the feature set.

Cepstrum has been used in speech analysis for pulse isolation and segmentation and is also claimed to have similar benefits as for the auto-correlogram. It is believed the cepstral features are capable of identifying partially or multiply overlapped pulses which are similar to the pulse trains that one observed during common AE inspection process. The cepstral domain has been added to the feature set in order to augment the capability of the feature set to reflect more physical phenomena.

A better pulse information extraction algorithm was added which describes the pulse in a more complete way. As a result, the feature set has since been augmented to a number of 87 compared to the original 30.

In order to accommodate this large number of features, Tektrend has upgraded its advanced NDE signal analysis package, SCANS, to meet the requirement.

3. PHASE III : LABORATORY DEMONSTRATION

The tasks of this phase also included development of an interactive data acquisition software package to work with the SLAM prototype unit. This design exercise required a lot of feedback for modification by actually using it in the welding shop. All preliminary drawbacks were noted in terms of user friendliness and responses to field and shop environments. Two laboratory tests and a hands-on work shop were set up during this phase of the project.

3.1 Laboratory Test #1

The first laboratory test provided a chance to evaluate the system to work as a linear source locator and data acquisition system. The test was held at CANMET. A 24" X 48" X 2" thick steel plate with a vee-groove in the center was used. Sulfur and copper were used to induce cracks in the weld bead. Over 2000 signals were gathered during different passes of the welding for analysis. Both linear source location and data logging were demonstrated successfully. Valuable information had been acquired on the use of the interactive data acqusisition software and subsequent modification of the software was made. Due to the large amount of data taken, the data analysis was done after the second test.

3.2 Laboratory Test #2

The second laboratory test provided a chance to evaluate the system in the planar source location mode,and the data acquisition system. The system was reevaluated based on the changes made since the first test. The same thick steel plate was used, new weld beads were laid on top with similar kind of defects induced. 4 channels were set up to locate AE emission sources. A very high degree of consistency had been observed with the detected and the actual flaw location found on the test specimen. The real time display of flaw clusters provided the operator a visual means to locate the flaw easily. The screen display provided a location resolution of better than $\pm$ 1" or approximately one transducer diameter for the test setup. More accurate location is also available for each individual event with resolution up to 0.625 mm. However, for pratical purposes, a statistical display of the most probable event location cluster is more useful than scattered high resolution location indications. The system is designed so the user can select the accuracy appropriate to his application.

More information was gathered on the use of the interactive data acquisition software and a new version of the program was written to reflect all the findings. Improved user interface, more reliable operation and better screen display were added to the new program as a result.

3.3 The Hands-On Work Shop

In order for the CANMET personnel to operate the system on their own, a hands-on week long work shop was held to provide the necessary training. It included training on both hardware and software. It also included the training in the use of the Tektrend SCANS package. In-depth details of the theory of operation of the SLAM prototype unit was given. It also provided a survey on the state of the art in NDT techniques.

3.4 Data Analysis

The data collected during the first laboratory test were processed and analyzed using the SCANS package. The AE signals originating from sulfur-induced cracking signals were analyzed along with background signals under normal welding of a perfect weldment.

The data were isolated using biggest pulse information in the time domain and power distribution in the frequency domain. The rise time is calculated as the time the signal crosses the base trigger level to the time it reaches its maximum peak level. For valid AE signals the rise time is usually around 25 micro second for this particular set up and the pulse width is about 60 micro second. For background noise the rise time is usually greater than 25 micro second and the pulse width is much bigger than 60 micro second.

The rise slope is calculated as the ratio of the maximum peak amplitude against the rise time. It has been observed the valid AE signal possesses rise slope in excess of 5 unit per micro second (in a 128 unit full scale) while background signals have a rise slope less than 1 unit per micro second.

In the frequency domain, valid AE signals usually have multiple peaks associated with the larger peak and the peak width is larger than those from a background noise signal. The high frequency end of the spectrum from a valid AE signal has more peaks and usually decays slower than those of a background noise signal.

The isolated signals were grouped into a training and a testing set, both containing AE signals originated from sulfur induced cracking and from bakcground operation noise. 87 features were extracted from each of these signals to form a feature data base and this data base was submitted to the SCANS package for analysis. All four types of classifiers were used in this analysis, namely, a Linear Disriminant Function, K-nearest Neighbor, Empirical Bayesian and Minimum Distance classifiers. An optimization was performed to obtain to best recogntion result from these signals by selecting different combinations of features. The final results indicating a combination of a subset of 30 features from a total of 87 features produced a very consistent and reasonably high (about 80%) recognition rate when applied to identify sulfur induced cracking signals from background noise. The following features were observed:

* Number of peaks in the time domain with zero crossing, 10 % peak amplitude crossing and 25% peak amplitude crossing were all selected.

* Peak location were generally selected for the first three largest peaks. Peak width defined as 90% peak amplitude end to end and area integrated under these peaks were also selected as well. Their relative positions, from largest peak to second largest peak, from largest peak to third largest peak, are also selected.

* Peak amplitude, rise time, pulse width of the third largest peak were selected.

* Number of peaks in the frequency domain with zero crossing, 10 % peak amplitude crossing and 25% peak amplitude crossing were all selected.

* The percentage area under the largest peak in the frequency domain was selected.

* The first two partial power distribution were selected.

* In the cepstral domain, the peak amplitude of the second largest peak and the percentage area of the largest peak were selected.

* In the auto-correlation domain, number of peaks with zero crossing and 10% peak amplitude crossing were selected.

* The second peak location in the auto-correlation domain was selected.

* 25-37.5% and 75-87.5% partial auto-partial-spectral distribution were selected in the auto-correlation domain.

Detailed descriptions of laboratory tests and compilations of data and analysis results are contained in a Technical Appendix to this report.

4. SUMMARY

It has been demonstrated that both the SLAM prototype unit and the interactive data acquisition software performed as required. With this functioning software and hardware system and the preliminary results obtained on controlled laboratory specimens the applicability of the pattern recognition for classification of AE signals originating during welding was confirmed on defects as reported.

The optimal feature subset contains features from all four domains. It justifies our proposal of adding these two new feature domains. It confirms their usefulness in classifying AE signal gathered during welding. If they were of no value to the process, they would be rejected by the system, as were the feaures from the general properties of the signal.

While the tests in this phase of the program, carried out at CAN/MET, established the ability to distinguish gross defect acoutic emission signals from process noise, there remains work required to evaluate the ability to distinguish among types of flaw indications and the level of sensitivity to flaw size. With regard to the level of pattern recognition itself, the task of fully exploring the usage of each individual feature with respect to the physical phenomena involved also requires further investigation.

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TECHNICAL APPENDIX

TO THE

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71 pp

DSS FILE NUMBER: 17SQ.23440-1-9038
DSS CONTRACT SERIAL NUMBER: 1SQ81-00067
CANMET SCIENTIFIC AUTHORITY: Mr. Victor Caron

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ACOUSTIC EMISSION MONITORING SYSTEM

FOR

WELDING THICK-WALLED VESSELS

PROJECT OVERVIEW

This project was undertaken to develop a monitoring system based upon the use of advanced pattern recognition and signal classification techniques to provide real-time process and quality control during the welding of thick-walled pressure vessels. It comprised a series of tasks falling into three phases. First, preliminary data acquisition was carried out on laboratory specimens and the data analyzed to establish feasibility and design criteria for the next two phases. The second phase involved design and construction of the monitoring system and the third phase field demonstration in the CANMET welding shops. Each phase is documented in this report.

During the course of the project, an amendment was executed changing the hardware configuration from a stand-alone unit to a more general laboratory research unit. An LSI 11/23 computer was supplied with the Signal Location and Aquisition Module (SLAM). The computing capability combined with Tektrend's proprietary System for Classification and Analysis of Nondestructive testing Signals (SCANS) makes the system a general purpose nondestructive testing signal analysis work-station as well as a weld monitoring unit.

This is a Technical Appendix to the Final Report and, to make this report self-contained, a background review on pattern recognition is provided. The first part of the report describes the first phase and the latter part the third phase. A technical description of the hardware is submitted in a separate SLAM 4000 Operating and Service Manual and the SCANS software in a separate Users Manual.

SIGNAL DISCRIMINATION REQUIREMENTS

Signal discrimination is fundamental to acoustic emission (AE) testing. The high sensitivity inherent in the AE detection method leads to problems disinguishing ambient background noise from signals corresponding to fault conditions. Basic discrimination methods involve bandpass filtering and threshold settings. Other methods include signal rise time and spatial discrimination. However, in many applications unwanted signals pass through the various windowing techniques and more powerful identification methods are required.

Pattern recognition methods provide a means through which positive signal sorting, classification and source identification can be effected. Several studies have demonstrated the potential of pattern recognition methods in analyzing acoustic emission signals. (1-10.)

Successful monitoring of acoustic emission signals in applications where signals are emitted continuously, such as in the welding processes or monitoring of material components under service conditions, is only possible if the acoustic signals associated with fault conditions can be recognized and correlated with their sources (11-14).

In traditional weldment inspection systems, decisions are based principally on human perception by examination of the amplitude and time profiles of AE signals. Such analysis is often subjectively dependent upon the operator's interpretive skills. Signal classification done by such methods may show variations attributable to level of experience, operator fatigue, both concentration and interest as well as the inescapable limits to human capability. The efficiency of non-destructive inspection is governed mainly by three related properties: reliability, sensitivity and accuracy. Automatic flaw-detection and interpretation can minimize or eliminate operator error and improve the reliability and efficiency of the discrimination process.

The common characteristics of AE signals which are used for monitoring structural integrity comprise the following:

1) Waveform, peak amplitude and frequency content of an AE signal which provide information on energy and time duration.

2) Emission rate and energy distribution of AE signals detected by a transducer, which provide micro-fracture and/or deformation information.

3) Relative signal arrival time intervals at several transducers and the consequent source location information which allows spatial identification of defective areas.

In monitoring welds for signs of crack initiation or propogation it is important to distinguish the AE signals which are caused by weld cracking from those which are caused by slag cracking and other general process noises.

Pattern recognition methods have great potential in sorting signals and identifying their emission source. Only recently have these techniques been applied to NDT evaluation (5-10). Various contributors have demonstrated the feasibility of applying pattern recognition techniques to classification of welding defects (11-15). These techniques analyze the digitized signal data in a pattern space composed of features in order to characterize the signals. The following section provides a brief overview of pattern recognition techniques.

PATTERN RECOGNITION TECHNIQUES

Pattern recognition techniques usually applied for signal characterization can be grouped into different categories according to their approach: linear, piece-wise linear, non-linear, parametric and non-parametric techniques. Likewise, the distribution of patterns can also be classified as linearly separable, non-linearly separable and piece-wise linearly separable as shown in Figure 1. Since there is no knowledge of how the AE signal classes are distributed, we have chosen three fundamental pattern recognition methods for analysis of AE signals: the linear discriminant function (LDFC) method (11-13) the minimum distance classification (MDC) method (11, 13, 14) and the K-nearest neighbor (KNNC) method (11, 13, 14). These classification methods cover linear, piece-wise linear, parametric and non-parametric techniques. The derivation of these three method is based on probability theory and the maximum likelihood assumption. A formal discription of these methods as applied to signal processing is given in (16).

FEATURE EXTRACTION

The AE signal waveform gathered from the inspection bears pertinent information either explicitly or implicitly related to the physical phenomena distinguishing the classes of defect to be recognized. Since there is no a priori knowledge of the best descriptors to use with regard to our problem, many types of waveform paremeters derived from the original signal are used in this study. These parameters can be grouped into several categories, namely, general properties and shape factors, time domain, pulse information, partial energy distribution in different frequency bands, and correlation coefficients. Table 1 shows all features extracted from AE signals. Not all features may be useful in discriminating the signal classes of interest, however to determine the best feature set among a number of waveform parameters, we developed a feature discrimination procedure. The procedure is based on intra-class and inter-class distances and uses a biserial correlation index to select the features. Figures 2 and 3 illustrate the distribution of a pair of features being investigated against their ability to distinguish between fracture mechanisms. Their respective distribution curves and biserial correlation indices are computed. As can be seen in the figures, if the feature distributions are highly overlapped, the biserial index is very low. On the other hand, if the distributions are widely separated, the biserial index is high. Using this decision rule, features with high biserial indices are selected and are used for classification.

AE SIGNAL CLASSIFIER

Based on the pattern recognition techniques and feature selection scheme outlined above, an on-line AE signal classification system as illustrated in Figure 4 has been designed and implemented. Since this classification system accepts waveform parameters as input it can be applied to classify many other types of NDT signals besides those from acoustic emission such as ultrasonic and eddy current signals. In this study, the system is used to detect welding defects as outlined in the next section.

System Description

SCANS is a self-contained modular software and hardware package for nondestructive evaluation signal analysis and interpretation. In a user-friendly environment, the non-computer, non-electronics oriented NDE specialist can design a powerful, customized computer system to interpret NDT signals in his particular applications. SCANS is an interactive, menu-driven, stand-alone system which provides all necessary software to synthesize, evaluate and implement the signal classifiers used to interpret signal indications from a variety of NDT methods.

The software is designed for use by NDE specialists and, while it incorporates powerful statistical analysis and artificial intellignet methods, no special knowledge of the latter is required. Similarly, no programming is required. Plain English commands and menus are used for easy and concise communication with the user. Multilevel menus lead the user through the whole course of data analysis and classifier development.

SCANS consists of five basic modules:

1. Feature Generation and Database Management Module.
2. Signal Preporcessing
3. Histogram Analysis
4. Clustering Analysis
5. Signal Classification

General description and overview

The **feature generation module** is used to extract a set of features from a signal data record. Because all the other modules accept only feature sets as input, the feature generation step is always the first stage of processing. The feature generation module is application-dependent. For example, to

analyze acoustic emission (AE) signals, the AE feature generation module must be used. Seperate modules are available for ultrasonic (UT) and eddy current signals. The feature generation module extracts features which reflect the physical properties of the signals under analysis.

The **histogram analysis module** allows first-order analysis of the ability of individual features to distinguish between various signal classes. Histograms plot features against number of samples per class, giving a graphic means for determaining the power of individual features. Simple correlation can be detected easily if there is a direct relationship between the feature and some distinguishing physical property.

The **clustering analysis module allows** second-order analysis of feature power. The clustering analysis module allows the user to explore the relationship between distinguishing physical properties and arbitrary combinations of features.

Classifier Module

The module is the heart of the system. The signal classification module allows a third-order analysis, using advanced pattern recognition techniques. This module combines the following four powerful classifiers into one package, allowing the use of linear, non-linear, statistical, and parametric techniques.

* linear discriminant function classifier
* k-nearest neighbor classifier
* empirical Bayesian classifier
* minimum distance classifier

This module facilitates the synthesis, evaluation and application of classifiers tailored to recognize and distinguish between various physical phenonmenon.

The classifier module executes under operator control all the necessary steps to synthesize any one to these classifiers for a given application. Once a particular classifier is synthesized, the user can redirect the system to evaluate the classifier using a different set of data. The setup of the classifier can be stored away for later use and on-line signal classification. During the synthesis procedure, the user can instruct the system to use different combinations of features based on previous feature analysis results. The feature sets either can be selected by the user, or they can be selected automatically by a built-in feature selection algorithm. The latter uses inter- and intra-class distances, correlation analysis and multi-class weighting coefficients to optimize feature set performance.

Feature Extraction Modules

The analysis and classification modules are independent of application and of the type of signal to be classified. For different applications only the feature extraction module has to be changed. Thus, these general-purpose programs can be used with a number of nondestructive evaluation methods such as acoustic emission, ultrasonics and eddy currents.

Preprocessing Module

The signal preprocessing module contains a set of highly interactive signal analysis routines for direct manipulation of NDT signals. This module is intended to be used by advanced and more sophisticated user to explore and design features for new applications of the SCANS system.

The module performs as a "waveform calculator", in which multiple registers allow storage, retrieval, and display of signal data, and facilitates fast and complicated signal operations. While displaying results graphically, the user can perform operations such as real and complex multiplication, division, logarithms, addition, substraction, and direct and inverse Fourier transforms. All operations are menu-driven, and complicated signal processing including deconvolution, correlation and cepstral analysis can all be achieved through selecting a few menu entries.

PRELIMIMARY EXPERIMENTS

AE signals of several kinds of welding defects were obtained from a 1020 mild steel block specimen by changing the welding parameters under controlled shop conditions as given in Table P2 and P3. Although lack of fusion was not expected to be an emission source per se, the objective was to monitor this condition to determine whether any associated phenomena yielded emission. The welds were produced by submerged arc deposition of a weld bead in a vee-groove in thick plate twelve inches in length. Beads were started on run-up tabs and completed on run-off tabs. Acoustic emission was monitored only during the time the electrode was on the plate itself. The transducers were placed under the plate.

System gain was set at 80 db and the threshold at 1.2 v. Acoustic emission was monitored in the 250 KHz to 500 KHz frequency range. Data were collected using an AET 3000 for signal conditioning and amplification and signals recorded on a Nicolet Model 204 digital oscilliscope at 5 MHz. The data were transmitted to an LSI 11/23 minicomputer and analyzed using the Tektrend SCANS pattern classifier program.

It was necessary to make several passes for each type of weld to obtain a satisfactory set of data for training and testing. Thus each data set consists of data obtained on several separate welds with nominally identical conditions.

However, the data sets do reflect the normal variations one would expect to find in setting shop instrumentation including instrument settings and coupling variations. Thus, the data sets incorporate some of the variability expected in actual application of these methods.

Using the thirty features shown in Table P1, two classification experiments were carried out with each of the three methods and the results compared. The same experiments were repeated using the best feature set obtained using the feature selection procedure described earlier. Table P4 summarizes the best feature set used in each of these three classifiers for these particular tests.

Two class problem:

a) Lack of Fusion, Sound Weld
b) Center Line Crack (CLC), Sound Weld

Two defect types and normal process noise (sound weld) both were classified using both the complete set of features as well as the best feature set.

PRELIMINARY TEST RESULTS

The classification results for each of the three classifiers is given in Tables P5 and P6 for all features and best feature set respectively.

1. Both training and testing results for all classifiers are good, which indicates that pattern recognition methods are useful in this application.

2. The MDC classifier gives the highest overall recognition rates, averaging 95.04% on testing samples.

3. The KNNC classifier is the only one to show improvement with best feature set, improving 16% over the recognition rate achieved with all features in use.

TABLE P1

WAVE FORM FEATURES EXTRACTED FROM ACOUSTIC EMISSION SIGNALS

PARAMETERS		DESCRIPTION
1)	STD	standard deviation of AE signal
2)	SKW	skewness coefficient (3rd moment) of AE signal
3)	KUR	kurtosis coefficient (4th moment) of AE signal
4)	CVA	coefficient of variation of AE signal
5)	RT1	rise time for the biggest pulse in time domain
6)	FT1	fall time for the biggest pulse in time domain
7)	PD1	pulse duration for the biggest pulse in time domain
8)	PW1	pulse width for the biggest pulse in time domain
9)	RT2	rise time for the 2nd biggest pulse in time domain
10)	FT2	fall time for the 2nd biggest pulse in time domain
11)	PD2	pulse duration for the 2nd biggest pulse in time domain
12)	PW2	pulse width for the 2nd biggest pulse in time domain
13)	PRT	pulse ratio of the 2 biggest pulse
14)	PIN	pulse distant of the 2 biggest pulse
15)	PS1	partial power in frequency band 0 - .25 MHZ
16)	PS2	partial power in frequency band .25 - .50 MHZ
17)	PS3	partial power in frequency band .50 - .75 MHZ
18)	PS4	partial power in frequency band .75 - 1.00 MHZ
19)	PS5	partial power in frequency band 1.00 - 1.25 MHZ
20)	PS6	partial power in frequency band 1.25 - 1.50 MHZ
21)	PS7	partial power in frequency band 1.50 - 1.75 MHZ
22)	PS8	partial power in frequency band 1.75 - 2.00 MHZ
23)	PMM	ratio of the 2 biggest partial powers
24)	PMN	ratio of the smallest and biggest partial powers
25)	FMR	frequency of largest peak in power spectrum
26)	RMX	amplitude of largest peak in power spectrum
27)	FQ1	frequency at which 25% of accumulated power was observed
28)	FQ2	frequency at which 50% of accumulated power was observed
29)	FQ3	frequency at which 75% of accumulated power was observed
30)	NPK	number of peaks exceeding a preset threshold

TABLE P2

CHARACTERISTICS OF WELDING SPECIMEN

WELDING SPECIMEN

MATERIAL : 1020 MILD STEEL BLOCK

DIMENSION: 6" X 3" X 24"

GROOVES : 20° X 3/4" EVERY 2"

ELECTRODE : 5/32" WIRE

TABLE P3

CLASSES OF DEFECTS USED FOR CATEGORIZATION

WELD TYPE	SPEED	CURRENT	VOLTAGE
SOUND WELD	6" / MIN.	325 AMP	30 V.
CENTERLINE	20" / MIN.	850 AMP	30 V.
LACK OF FUSION	28" / MIN.	850 AMP	34 V.
CRATER CRACK	11" / MIN.	450 AMP	30 V.

TABLE P4

BEST FEATURE SET USED IN THREE-CLASS PROBLEM

FOR TRAINING THREE CLASSIFIER

	CLASSIFIER		
PARAMETERS	LDFC	KNNC	MDC
1) STD			
2) SKW			
3) KUR			
4) CVA			
5) RT1	Y		Y
6 FT1	Y	Y	Y
7) FD1	Y		Y
8) PW1	Y	Y	Y
9) RT2			
10) FT2			
11) PD2			
12) PW2			
13) PRT			
14) PIN			
15) PS1	Y		Y
16) PS2			
17) PS3	Y		Y
18) PS4			
19) PS5	Y		Y
20) PS6			
21) PS7	Y		Y
22) PS8			
23) PMM			
24) PMN	Y		Y
25) FMR	Y	Y	Y
26) RMX	Y		Y
27) FQ1	Y	Y	Y
28) FQ2	Y		Y
29) FQ3	Y		Y
30) NPK	Y	Y	Y

Y Implies the feature took part in classification.

TABLE P5

TWO-CLASS SIGNAL CLASSIFCATION PROBLEM WITH ALL FEATURES IN USE

		CLASSIFIER		
		LDFC	KNNC	MDC
		(Recognition Rates in Percentage)		
TYPE				
LACK	(TRAINING)	81.25	100.00	87.50
SOUND		94.74	94.74	94.74
	OVERALL :	88.57	97.14	91.43
LACK	(TESTING)	81.82	81.82	100.00
SOUND		93.33	80.00	93.33
	OVERALL :	88.46	80.77	96.15
CLC	(TRAINING)	94.74	100.00	89.47
SOUND		100.00	100.00	94.74
	OVERALL :	97.37	100.00	92.11
CLC	(TESTING)	94.44	83.33	88.89
SOUND		100.00	93.33	100.00
	OVERALL :	96.97	87.88	93.94

TABLE P6

TWO-CLASS SIGNAL CLASSIFICATION PROBLEM WITH BEST FEATURE SET IN USE

TYPE		CLASSIFIER		
		LDFC	KNNC	MDC
		(Recognition Rates in Percentage)		
LACK SOUND	(TRAINING)	81.25 94.74	93.75 100.00	81.25 94.74
	OVERALL :	88.57	97.14	88.57
LACK SOUND	(TESTING)	81.82 93.33	100.00 93.33	100.00 93.33
	OVERALL :	88.46	96.15	96.15
CLC SOUND	(TRAINING)	94.74 94.74	100.00 100.00	89.47 94.75
	OVERALL :	94.74	100.00	92.11
CLC SOUND	(TESTING)	94.44 100.00	83.33 100.00	88.89 100.00
	OVERALL :	96.97	90.91	93.94

FIELD TESTS OF THE SLAM-4000

Two series of field tests were carried out at CANMET and a workshop on SCANS at Tektrend. These activities are summarized on page 17.

FIELD TEST #1

During the first field test of the SLAM-4000 unit (Weld Monitor Work Station), over 2,000 signals were gathered during several welding passes on a 24"X48"X2" thick steel plate (Figure 1). Sulfur and copper were used to induce cracks in the bead. Since there was no previous practical experience of the SLAM-4000, this was a trial test.

The SLAM-4000 data acquisition software was originally designed based on laboratory simulated situations. This first field test provided valuable information on the impact of the field environment upon the effectiveness of potential SLAM operating. The following points were observed ---

* The question and answer approach to control of the various internal settings of SLAM-4000 was found to be too time consumming and lengthy. It was especially difficult when one tried to alter the system set ups to match a rapidly changing situation. A more direct and simplified means was recommended to control the hardware parameters, such as gains, trigger, dead time, etc.

* Data overflow protection is essential for acquiring vast amounts of data. This is particularily true for ultra-high speed data transmission (the SLAM-4000 sends over 1.5 milllions bytes of data per second between the digitizer and the computer main memory). For the first two runs of the weld passes, a very high gain on the signal was used and the system was very sensitive. It toke in a large amount of data over a very short period of time and exceeded the preset limits of the system. As a result the system crashed and data were lost. More checking and protection procedures were recommended to prevent such situation from occuring in the future.

* The lack of hard copies of the source location display made it difficult to document the result of the test. A screen dump of the histogram display to an external line printer was recommended for the next revision of the software.

* The first version of the program made use of the graphic facilities on the VT105 terminal to display the acquired data. However, there is no provision to display the signal on the regular VT100 alpha-numeric terminal. It makes it very difficult to calibrate the system without a graphic terminal. Line drawing graphic symbols were recommended to be used to display the signal profile in a simplified way.

In spite of the above recommendations for improvements, over 2,000 signals were gathrered. However, these signals were captured whenever the signal level exceeds the trigger threshold value and no spatial isolation was imposed on the acception of the digitized data. This is mainly because there was no a priori knowledge of the nature of the welding signal, and it was decided to accept more data than risk missing the one that really refected the physical phenomena of the cracking mechanism. This accounts for the large amount of data acquired during this particular test. Although we can visualize the correlation between the histogram display and the defect locations, there was still a certain amount of randomly scattered noise due to the inherent nature of dual channel location scheme which cannot distinguish between direct and rebounded signals from the emission source. A three or four channel set up is more discriminating because the rebounded signal will be rejected by the extra transducer available. A second field test is thus secheduled to exploit the planar location capability using 4 channel of signal inputs.

SUMMARY OF FIELD TEST AND WORKSHOP ACTIVITY

DATE : 18-OCT-84
PLACE : CANMET/EMR

First Field Test of the Weld Monitor Work Station

TASK :

. Demonstrate dual channel linear source location

. Demonstrate digitization and acquisition of AE signals

. Gather information on shop and field environment and their impacts on the operation of both hardware and software systems for possible modification and improvement.

. Collect weld defect signal data for analysis

DATE : 5-NOV-84
PLACE : CANMET/EMR

Second Field Test of the Weld Monitor Work Station

TASK :

. Demonstrate four channel planar source location

. Demonstrate improvement of data acquistion software and gather feedback on possible further modification and improvement of the system

DATE : 17-DEC-84 TO 21-DEC-84
PLACE : TEKTREND

Training Work Shop

TASK :

. Provide necessary training for the CANMET/EMR personnel to operate the Weld Monitor Work Station hardware and software system

. Provide indepth details of the theory of operation of both hardware and software of the SLAM/SCANS system

. Provide a survey on the state of the art in NDT techniques

. Allow the CANMET/EMR personnel to have a hands-on experience with both hardware and software

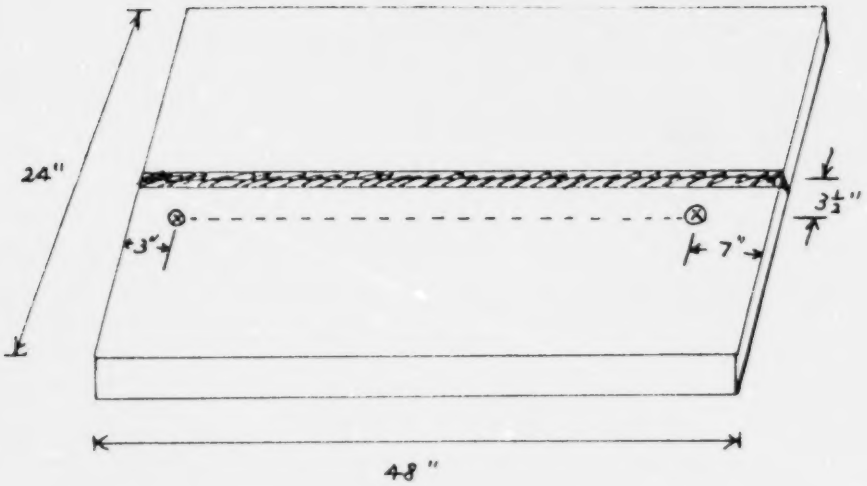

FIGURE 1 TEST #1 SETUP

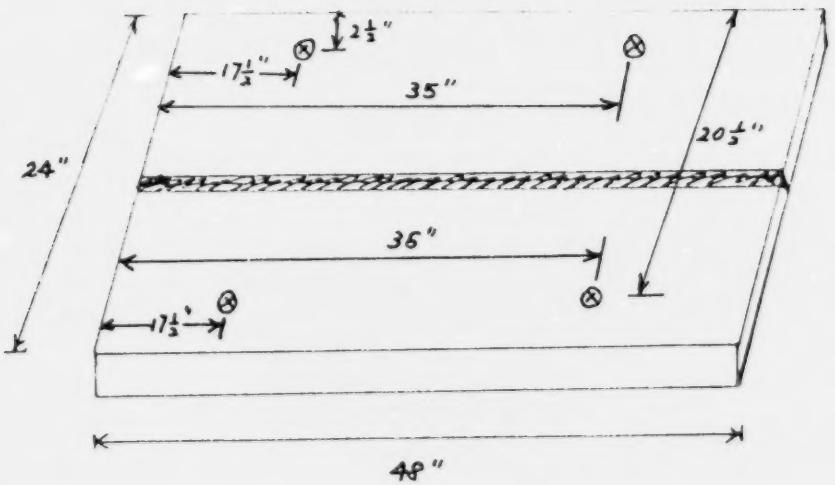

FIGURE 2 TEST #2 SETUP

FIELD TEST #2

Both the SLAM-4000 hardware and software system were upgraded and modified to refect all the findings and recommendations observed during the first field test. The main objective of the second field test was to demonstrate and test the four-channel planar source location capability of the system. A similar set up as in test #1 was used except four transducers were used instead of two (as shown in Figure 2). Several runs of weld passes were produced with sulfur- and copper-induced cracks. The modified software allowed more direct control over the internal settings of the hardware. A two-dimensional mapping display was used to continuously refresh the detected flaw locations on the terminal screen during the welding test. A very high degree of consistency had been observed with the detected and the actual flaw location found on the test specimen. In many instances, the location mapping was actually used to assist to locate the cracks in the bead. Compared to the dual-channel linear source location, as used in the first field test, the four-channel planar source location mechanism provided a superb immunity to noise and signals originating outside the test grid set up. The flaw location mapping display was clean and the location indication well defined as opposed to the scatter observed in the previous test.

As a result, planar location was incorporated into the next modification of our software as an effective means to isolate valid AE signals from unwanted noise signals. The problem of taking in an unreasonably large amount of digitized signal, as in the first test, would be avoided.

More feedback and comments were gathered concerning the format and user interface of the software. Certain inconveniences of using the package were noted :

* The planar flaw location mapping was useful; however, it was hard to read.
* There was no default start up setting. The user has to set up the system each time.
* There was no easy way to find out the settings and status of SLAM once it is set.
* There was no checking of existing files and there was a chance of over-writing into a old data file.

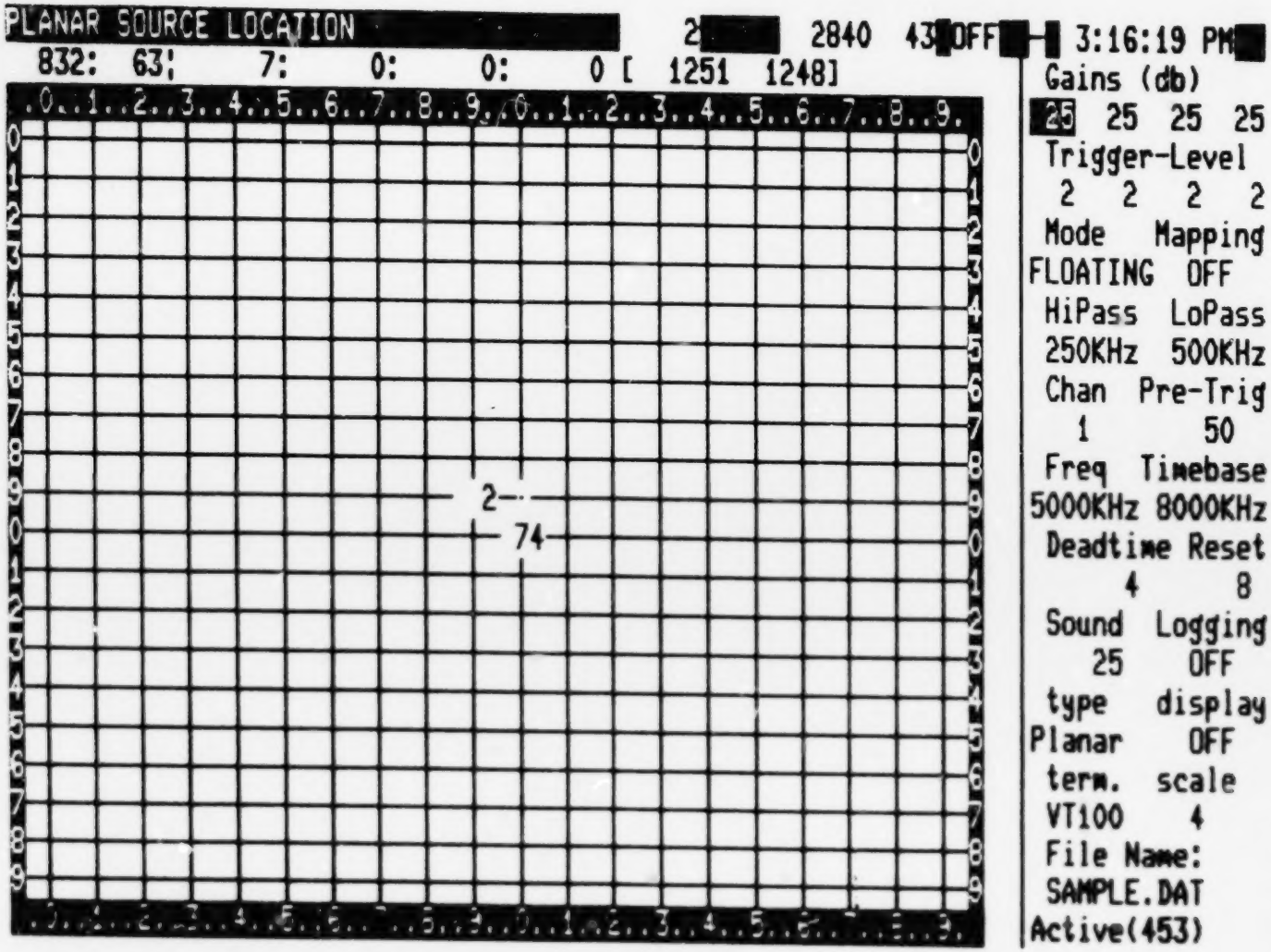

FIGURE 3 SAMPLE SCREEN DISPLAY

THE POST FIELD TEST PERIOD

SOFTWARE UPGRADE

After these two field tests, the SLAM control and acquisition program was redesigned and improved to overcome all the shortcomings encountered. The new version of the software was demonstrated to the CANMET/EMR personnel during the 5-day work shop period. The new program incorporates more advanced features not availabe under the old version; the following summarizes a few of the improvements (also refers to Figure 3) ---

- Dedicated key approach, most functions and controls are selected by a single key stroke on the key pad.
- Instantaneous display of changes of system status and internal and default SLAM control settings. All changes are reflected in real time.
- All acceptable control values are prestored in the program. The user selects the values rather than entering it. This improves response time as well as prevents erratic value input.
- Set up values and status are displayed in text form. Confusion and misunderstanding are prevented.
- The program now initializes the SLAM hardware using user preset default values. The default file can be altered by the user.
- The location mapping display is improved to include grids and actual coordinates values.
- A screen dump to external printer for both location mapping and system set up status is added.
- The data acquisition portion of the program now checks for existing files and computes maximum allowable storage size and automatically stops taking in data when the limit is exceeded.
- Data file name and file status and size is now displayed on screen.
- Keys have been added to allow toggling data logging, location mapping, delta-t display, etc., through a single key stroke on the key pad.
- The user can select to display signal amplitude profile on a regular alphanumeric terminal using line graphic symbols.

	TOTAL	SATURATED	AE	NOISE
PASS #1	-	-	-	-
PASS #2	-	-	-	-
PASS #3	114	24	18	72
PASS #4	82	8	6	68
PASS #5	226	94	16	118
PASS #6	266	66	12	188
PASS #7	152	18	2	132
PASS #8	44	-	12	32
PASS #9	242	42	8	192
PASS #10	86	18	10	58
PASS #11	76	-	20	56
PASS #12	82	-	24	58
PASS #13	64	-	20	44
PASS #14	64	-	30	34
PASS #15	70	-	22	48
PASS #16	70	-	26	44

TABLE 1 DATA SET BREAKDOWN

SIGNAL ANALYSIS

From the 2000 plus signals gathered during the first field test, it was observed that there are two major types of signals --- the background noise signal from operation of the welding machine and AE signals originating from defects. From an overview of the experimental log of the test (see Appendix I), it was noted that most of the defects were sulfur-induced cracks (center line, transverse, logitudinal cracks). As mentioned previously, these signal data were gathered with no spatial isolation or noise discrimination. Therefore, each data set consists of both type of signal. A conventional approach was used to pick out the valid AE signals from each of these data sets. The following criteria were employed :

- Rise time and rise slope of the signal
  Valid AE signals usually have a more structured signal envelope and a sharp rise time.

- Pulse shape and location
  Valid AE signals usually have a damped decay signal envelope with the largest peak upfront.

- Energy concentration
  Noise signals usually have a less structured energy concentration and lack high frequency components.

By using these criteria, each signal was inspected manually through display of both time and frequency domain on a graphic terminal. All signals with saturated amplitudes were first discarded from the data set, then the rest were separated based on the above rules. All 2000 plus signals were inspected one at a time. There are about 6 % of the total number of signals fall into the valid AE signal category. Samples of valid and invalid AE signals were given in Figure 4,5,6 and 7 together with their power spectrum. More samples were included in Appendix II.

The number of signals and the break downs of each data set is given in Table I. Because of the differences in system set up, two matched data sets, PASS #5 AND PASS #6, were selected to be analyzed by the SCANS software package.

Both PASS #5 and #6 were gathered during sulfur-induced cracking. For PASS #5, there are 16 valid AE signals found, while PASS #6 has 12 valid AE signals. On both passes, center-line and transverse cracks had been observed.

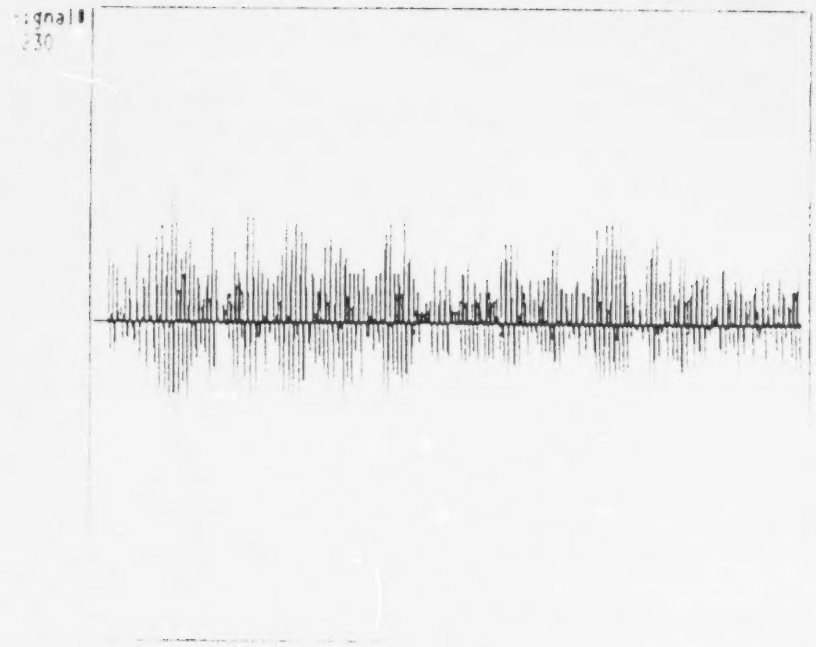

FIGURE 4 SAMPLE NOISE SIGNAL

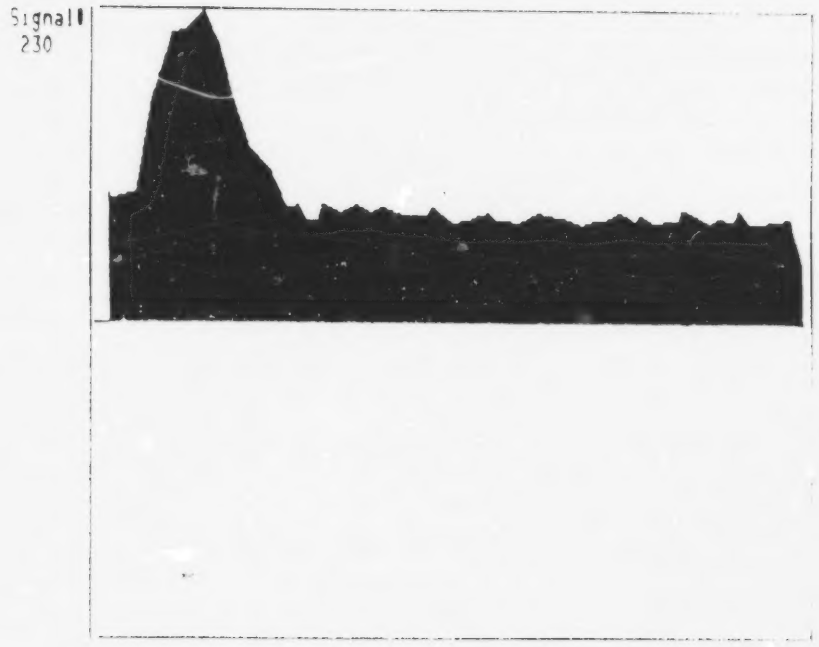

FIGURE 5 POWER SPECTRUM OF NOISE SIGNAL

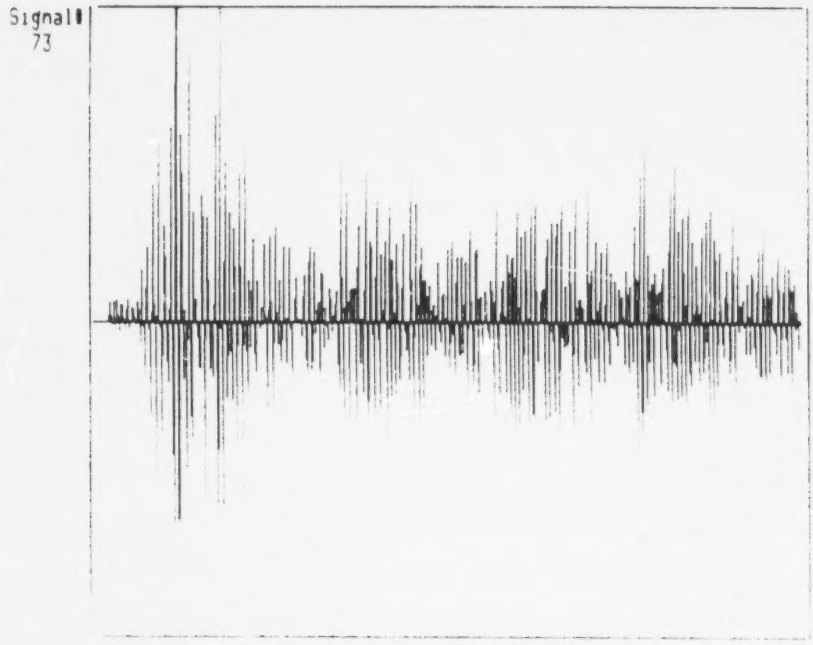

FIGURE 6 SAMPLE VALID AE SIGNAL

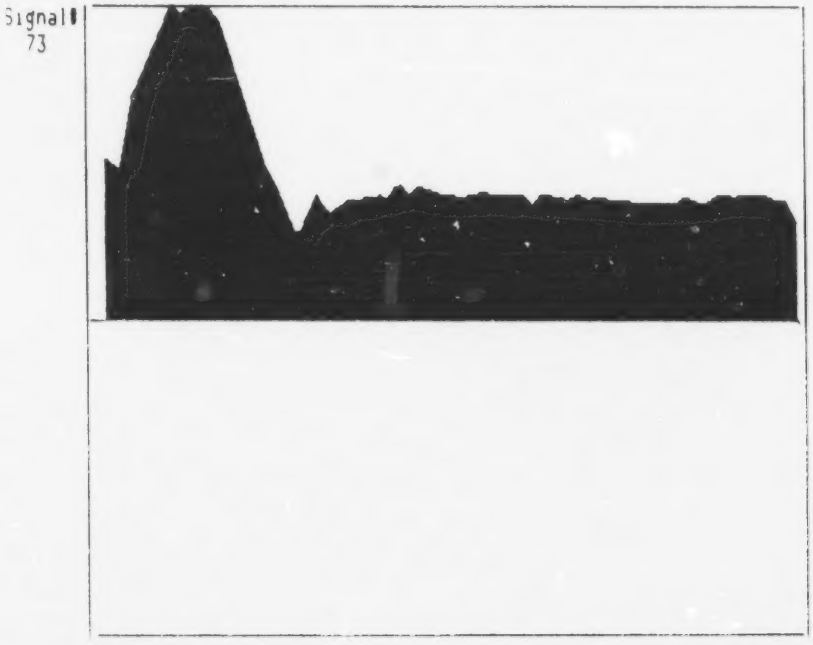

FIGURE 7 POWER SPECTRUM OF AE SIGNAL

For signal classification, it is important to prevent data over-fitting and under-fitting of a particular type of signal. In this test, there are many more background noise signals than valid AE signals. The background noise signal was limited to a comparable number with their valid AE signal counterparts. As a result, the following were used :

PASS #5

Background noise signal : 24 samples
Valid AE signal : 16 samples

PASS #6

Background noise signal : 30 samples
Valid AE signal : 12 samples

These signals were fed into an automatic feature extraction program and a list of 87 features were produced for each signal. Features from 4 different domains derived from the original signal were used.

- Time Amplitude and Signal Envelope
- Power and frequency
- Cepstrum
- Auto-correlation

This feature data base was then used in the signal classification analysis. Signals from PASS #5 were used for classifier training and signals from PASS #6 were used for evaluation. Four different signal classifiers were used in this test, namely,

- Linear discriminant function classifier
- K-nearest neighbour classifier
- Empirical Bayesian classifier
- Minimum distance classifier

LINEAR DISCRIMINANT FUNCTION CLASSIFIER

RESULT OF CLASSIFICATION

ID	SIZE	CONFUSION TABLE CLASS	1	2	3	4	RECOGNITION RATE
NOISE	24	1	20	4	0	0	83.33 %
S-INCL	16	2	6	10	0	0	62.50 %

OVERALL RECOGNITION RATE IS 75.00 %

87 FEATURES IN USE (MARKED WITH "*") --

F01* F02* F03* F04* F05* F06* F07* F08* F09* F10* F11* F12* F13* F14* F15*
F16* F17* F18* F19* F20* F21* F22* F23* F24* F25* F26* F27* F28* F29* F30*
F31* F32* F33* F34* F35* F36* F37* F38* F39* F40* F41* F42* F43* F44* F45*
F46* F47* F48* F49* F50* F51* F52* F53* F54* F55* F56* F57* F58* F59* F60*
F61* F62* F63* F64* F65* F66* F67* F68* F69* F70* F71* F72* F73* F74* F75*
F76* F77* F78* F79* F80* F81* F82* F83* F84* F85* F86* F87*

LINEAR DISCRIMINANT FUNCTION CLASSIFIER

RESULT OF TESTING

ID	SIZE	CONFUSION TABLE CLASS	1	2	3	4	RECOGNITION RATE
NOISE	30	1	24	6	0	0	80.00 %
S-INCL	12	2	2	10	0	0	83.33 %

OVERALL RECOGNITION RATE IS 80.95 %

87 FEATURES IN USE (MARKED WITH "*") --

F01* F02* F03* F04* F05* F06* F07* F08* F09* F10* F11* F12* F13* F14* F15*
F16* F17* F18* F19* F20* F21* F22* F23* F24* F25* F26* F27* F28* F29* F30*
F31* F32* F33* F34* F35* F36* F37* F38* F39* F40* F41* F42* F43* F44* F45*
F46* F47* F48* F49* F50* F51* F52* F53* F54* F55* F56* F57* F58* F59* F60*
F61* F62* F63* F64* F65* F66* F67* F68* F69* F70* F71* F72* F73* F74* F75*
F76* F77* F78* F79* F80* F81* F82* F83* F84* F85* F86* F87*

TABLE 2 TRAINING & TESTING RESULTS OF LINEAR DISCRIMINANT FUNCTION CLASSIFIER.

K-NEAREST NEIGHBOUR CLASSIFIER

RESULT OF CLASSIFICATION

		CONFUSION TABLE					
ID	SIZE	CLASS	1	2	3	4	RECOGNITION RATE
NOISE	24	1	23	1	0	0	95.83 %
S-INCL	16	2	9	7	0	0	43.75 %

OVERALL RECOGNITION RATE IS 75.00 %

87 FEATURES IN USE (MARKED WITH '*') --

F01* F02* F03* F04* F05* F06* F07* F08* F09* F10* F11* F12* F13* F14* F15*
F16* F17* F18* F19* F20* F21* F22* F23* F24* F25* F26* F27* F28* F29* F30*
F31* F32* F33* F34* F35* F36* F37* F38* F39* F40* F41* F42* F43* F44* F45*
F46* F47* F48* F49* F50* F51* F52* F53* F54* F55* F56* F57* F58* F59* F60*
F61* F62* F63* F64* F65* F66* F67* F68* F69* F70* F71* F72* F73* F74* F75*
F76* F77* F78* F79* F80* F81* F82* F83* F84* F85* F86* F87*

K-NEAREST NEIGHBOUR CLASSIFIER

RESULT OF TESTING

		CONFUSION TABLE					
ID	SIZE	CLASS	1	2	3	4	RECOGNITION RATE
NOISE	30	1	28	2	0	0	93.33 %
S-INCL	12	2	6	6	0	0	50.00 %

OVERALL RECOGNITION RATE IS 80.95 %

87 FEATURES IN USE (MARKED WITH '*') --

F01* F02* F03* F04* F05* F06* F07* F08* F09* F10* F11* F12* F13* F14* F15*
F16* F17* F18* F19* F20* F21* F22* F23* F24* F25* F26* F27* F28* F29* F30*
F31* F32* F33* F34* F35* F36* F37* F38* F39* F40* F41* F42* F43* F44* F45*
F46* F47* F48* F49* F50* F51* F52* F53* F54* F55* F56* F57* F58* F59* F60*
F61* F62* F63* F64* F65* F66* F67* F68* F69* F70* F71* F72* F73* F74* F75*
F76* F77* F78* F79* F80* F81* F82* F83* F84* F85* F86* F87*

TABLE 3 TRAINING & TESTING K-NEAREST NEIGHBOUR CLASSIFIER.

EMPIRICAL BAYESIAN CLASSIFIER

RESULT OF CLASSIFICATION

ID	SIZE	CONFUSION TABLE CLASS	1	2	3	4	RECOGNITION RATE
NOISE	24	1	14	10	0	0	58.33 %
S-INCL	16	2	1	15	0	0	93.75 %

OVERALL RECOGNITION RATE IS 72.50 %

87 FEATURES IN USE (MARKED WITH "*") --

F01* F02* F03* F04* F05* F06* F07* F08* F09* F10* F11* F12* F13* F14* F15*
F16* F17* F18* F19* F20* F21* F22* F23* F24* F25* F26* F27* F28* F29* F30*
F31* F32* F33* F34* F35* F36* F37* F38* F39* F40* F41* F42* F43* F44* F45*
F46* F47* F48* F49* F50* F51* F52* F53* F54* F55* F56* F57* F58* F59* F60*
F61* F62* F63* F64* F65* F66* F67* F68* F69* F70* F71* F72* F73* F74* F75*
F76* F77* F78* F79* F80* F81* F82* F83* F84* F85* F86* F87*

EMPIRICAL BAYESIAN CLASSIFIER

RESULT OF TESTING

ID	SIZE	CONFUSION TABLE CLASS	1	2	3	4	RECOGNITION RATE
NOISE	30	1	24	6	0	0	80.00 %
S-INCL	12	2	0	12	0	0	100.00 %

OVERALL RECOGNITION RATE IS 85.71 %

87 FEATURES IN USE (MARKED WITH "*") --

F01* F02* F03* F04* F05* F06* F07* F08* F09* F10* F11* F12* F13* F14* F15*
F16* F17* F18* F19* F20* F21* F22* F23* F24* F25* F26* F27* F28* F29* F30*
F31* F32* F33* F34* F35* F36* F37* F38* F39* F40* F41* F42* F43* F44* F45*
F46* F47* F48* F49* F50* F51* F52* F53* F54* F55* F56* F57* F58* F59* F60*
F61* F62* F63* F64* F65* F66* F67* F68* F69* F70* F71* F72* F73* F74* F75*
F76* F77* F78* F79* F80* F81* F82* F83* F84* F85* F86* F87*

TABLE 4 TRAINING & TESTING EMPIRICAL BAYESIAN CLASSIFIER.

MINIMUM DISTANCE CLASSIFIER

RESULT OF CLASSIFICATION

ID	SIZE	CONFUSION TABLE CLASS	1	2	3	4	RECOGNITION RATE
NOISE	24	1	19	5	0	0	79.17 %
S-INCL	16	2	6	10	0	0	62.50 %

OVERALL RECOGNITION RATE IS 72.50 %

87 FEATURES IN USE (MARKED WITH "*") --

F01* F02* F03* F04* F05* F06* F07* F08* F09* F10* F11* F12* F13* F14* F15*
F16* F17* F18* F19* F20* F21* F22* F23* F24* F25* F26* F27* F28* F29* F30*
F31* F32* F33* F34* F35* F36* F37* F38* F39* F40* F41* F42* F43* F44* F45*
F46* F47* F48* F49* F50* F51* F52* F53* F54* F55* F56* F57* F58* F59* F60*
F61* F62* F63* F64* F65* F66* F67* F68* F69* F70* F71* F72* F73* F74* F75*
F76* F77* F78* F79* F80* F81* F82* F83* F84* F85* F86* F87*

MINIMUM DISTANCE CLASSIFIER

RESULT OF TESTING

ID	SIZE	CONFUSION TABLE CLASS	1	2	3	4	RECOGNITION RATE
NOISE	30	1	24	6	0	0	80.00 %
S-INCL	12	2	2	10	0	0	83.33 %

OVERALL RECOGNITION RATE IS 80.95 %

87 FEATURES IN USE (MARKED WITH "*") --

F01* F02* F03* F04* F05* F06* F07* F08* F09* F10* F11* F12* F13* F14* F15*
F16* F17* F18* F19* F20* F21* F22* F23* F24* F25* F26* F27* F28* F29* F30*
F31* F32* F33* F34* F35* F36* F37* F38* F39* F40* F41* F42* F43* F44* F45*
F46* F47* F48* F49* F50* F51* F52* F53* F54* F55* F56* F57* F58* F59* F60*
F61* F62* F63* F64* F65* F66* F67* F68* F69* F70* F71* F72* F73* F74* F75*
F76* F77* F78* F79* F80* F81* F82* F83* F84* F85* F86* F87*

TABLE 5 TRAINING & TESTING MINIMUM DISTANCE CLASSIFIER.

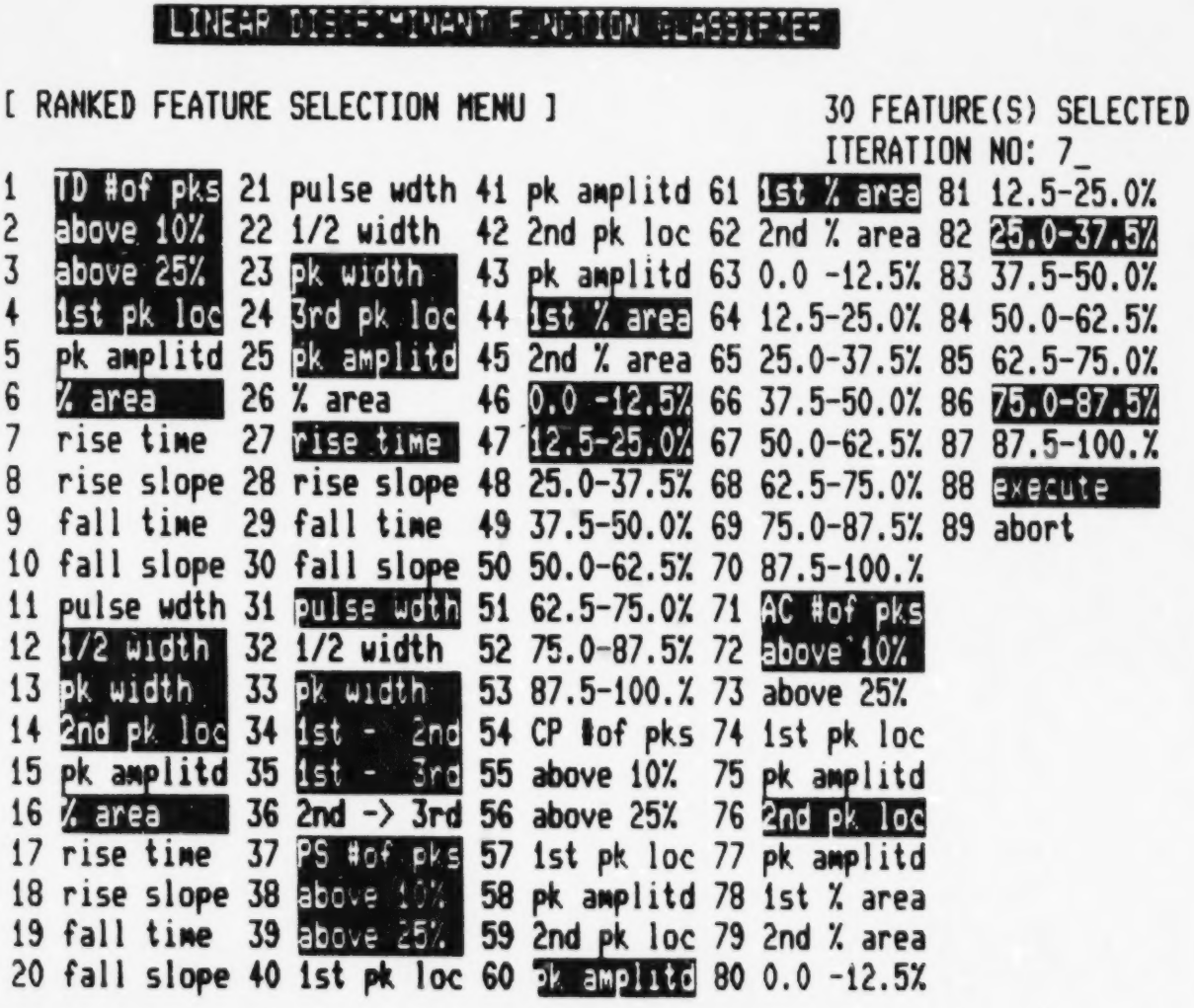

FIGURE 8 LISTING OF OPTIMAL FEATURE SUBSET

These four classifiers represent linear, non-linear, parametric and probabilistic methods used in signal classifications. The importance of using several types of classification methods is to ensure the reliability of the results obtained. Because this test used a small number of signals for training and testing, a consistant recognition performance for all four classifiers is an essential proof of the validity of the result.

At first all features were used in training and testing of all four classifiers. All four classifiers produce recognition rates in the mid 70% in the training phase and low 80% recognition rates in the testing phase. These results were summarized in Table 2, 3, 4 and 5.

Through selecting different combination of the features, better classifiers were synthesized. With the help of the built in feature analysis and many runs of trial and error, a subset of 30 feature from the 87 (Figure 8) were selected, reasonably high recognition rates were observed in both training and testing of all four classififers. Many of the training recognition rates have been boosted to the mid 90% range while the test recognition rates remains at the mid 80%. However, it has been observed that the recognition rate of the flaw has been improved sustaintially over the previous result. In some cases, 100% recognition rate on the defect was observed. Table 6, 7, 8 and 9 summarize the recognition results for both trainign and testing using these optimal set of feature.

On the preliminary data sets recognition rates of in excess of 80% are obtainable with all classifiers upon testing.

The empirical Bayesian classifier was capable of reducing Type I errors to zero giving 100% recognition of flaw indications while a 20% Type II error rate. The K-Nearest Neighbour classifier produced an opposite result giving a 50% Type I error rate and 6.66% Type II error rate. The results demonstrate not only the capability of optimizing the recognition rate but also of controlling the type of error to which error can be assigned.

LINEAR DISCRIMINANT FUNCTION CLASSIFIER

RESULT OF CLASSIFICATION

ID	SIZE	CONFUSION TABLE CLASS	1	2	3	4	RECOGNITION RATE
NOISE	24	1	23	1	0	0	95.83 %
S-INCL	16	2	2	14	0	0	87.50 %

OVERALL RECOGNITION RATE IS 92.50 %

30 FEATURES IN USE (MARKED WITH "*") --

F01* F02* F03* F04* F05 F06* F07 F08 F09 F10 F11 F12* F13* F14* F15
F16* F17 F18 F19 F20 F21 F22 F23* F24* F25* F26 F27* F28 F29 F30
F31* F32 F33* F34* F35* F36 F37* F38* F39* F40 F41 F42 F43 F44* F45
F46* F47* F48 F49 F50 F51 F52 F53 F54 F55 F56 F57 F58 F59 F60*
F61* F62 F63 F64 F65 F66 F67 F68 F69 F70 F71* F72* F73 F74 F75
F76* F77 F78 F79 F80 F81 F82* F83 F84 F85 F86* F87

LINEAR DISCRIMINANT FUNCTION CLASSIFIER

RESULT OF TESTING

ID	SIZE	CONFUSION TABLE CLASS	1	2	3	4	RECOGNITION RATE
NOISE	30	1	25	5	0	0	83.33 %
S-INCL	12	2	3	9	0	0	75.00 %

OVERALL RECOGNITION RATE IS 80.95 %

30 FEATURES IN USE (MARKED WITH "*") --

F01* F02* F03* F04* F05 F06* F07 F08 F09 F10 F11 F12* F13* F14* F15
F16* F17 F18 F19 F20 F21 F22 F23* F24* F25* F26 F27* F28 F29 F30
F31* F32 F33* F34* F35* F36 F37* F38* F39* F40 F41 F42 F43 F44* F45
F46* F47* F48 F49 F50 F51 F52 F53 F54 F55 F56 F57 F58 F59 F60*
F61* F62 F63 F64 F65 F66 F67 F68 F69 F70 F71* F72* F73 F74 F75
F76* F77 F78 F79 F80 F81 F82* F83 F84 F85 F86* F87

TABLE 6 TRAINING & TESTING RESULTS USING OPTIMAL FEATURE SET.
(LINEAR DISCRIMINANT FUNCTION CLASSIFIER)

K-NEAREST NEIGHBOUR CLASSIFIER

RESULT OF CLASSIFICATION

ID	SIZE	CONFUSION TABLE CLASS	1	2	3	4	RECOGNITION RATE
NOISE	24	1	24	0	0	0	100.00 %
S-INCL	16	2	2	14	0	0	87.50 %

OVERALL RECOGNITION RATE IS 95.00 %

30 FEATURES IN USE (MARKED WITH "*") --

F01* F02* F03* F04* F05 F06* F07 F08 F09 F10 F11 F12* F13* F14* F15
F16* F17 F18 F19 F20 F21 F22 F23* F24* F25* F26 F27* F28 F29 F30
F31* F32 F33* F34* F35* F36 F37* F38* F39* F40 F41 F42 F43 F44* F45
F46* F47* F48 F49 F50 F51 F52 F53 F54 F55 F56 F57 F58 F59 F60*
F61* F62 F63 F64 F65 F66 F67 F68 F69 F70 F71* F72* F73 F74 F75
F76* F77 F78 F79 F80 F81 F82* F83 F84 F85 F86* F87

K-NEAREST NEIGHBOUR CLASSIFIER

RESULT OF TESTING

ID	SIZE	CONFUSION TABLE CLASS	1	2	3	4	RECOGNITION RATE
NOISE	30	1	23	7	0	0	76.67 %
S-INCL	12	2	2	10	0	0	83.33 %

OVERALL RECOGNITION RATE IS 78.57 %

30 FEATURES IN USE (MARKED WITH "*") --

F01* F02* F03* F04* F05 F06* F07 F08 F09 F10 F11 F12* F13* F14* F15
F16* F17 F18 F19 F20 F21 F22 F23* F24* F25* F26 F27* F28 F29 F30
F31* F32 F33* F34* F35* F36 F37* F38* F39* F40 F41 F42 F43 F44* F45
F46* F47* F48 F49 F50 F51 F52 F53 F54 F55 F56 F57 F58 F59 F60*
F61* F62 F63 F64 F65 F66 F67 F68 F69 F70 F71* F72* F73 F74 F75
F76* F77 F78 F79 F80 F81 F82* F83 F84 F85 F86* F87

TABLE 7 TRAINING & TESTING RESULTS USING OPTIMAL FEATURE SET.
(K-NEAREST NEIGHBOUR CLASSIFIER)

EMPIRICAL BAYESIAN CLASSIFIER

RESULT OF CLASSIFICATION

ID	SIZE	CONFUSION TABLE CLASS	1	2	3	4	RECOGNITION RATE
NOISE	24	1	19	5	0	0	79.17 %
S-INCL	16	2	1	15	0	0	93.75 %

OVERALL RECOGNITION RATE IS 85.00 %

30 FEATURES IN USE (MARKED WITH "*") --

F01* F02* F03* F04* F05 F06* F07 F08 F09 F10 F11 F12* F13* F14* F15
F16* F17 F18 F19 F20 F21 F22 F23* F24* F25* F26 F27* F28 F29 F30
F31* F32 F33* F34* F35* F36 F37* F38* F39* F40 F41 F42 F43 F44* F45
F46* F47* F48 F49 F50 F51 F52 F53 F54 F55 F56 F57 F58 F59 F60*
F61* F62 F63 F64 F65 F66 F67 F68 F69 F70 F71* F72* F73 F74 F75
F76* F77 F78 F79 F80 F81 F82* F83 F84 F85 F86* F87

EMPIRICAL BAYESIAN CLASSIFIER

RESULT OF TESTING

ID	SIZE	CONFUSION TABLE CLASS	1	2	3	4	RECOGNITION RATE
NOISE	30	1	24	6	0	0	80.00 %
S-INCL	12	2	0	12	0	0	100.00 %

OVERALL RECOGNITION RATE IS 85.71 %

30 FEATURES IN USE (MARKED WITH "*") --

F01* F02* F03* F04* F05 F06* F07 F08 F09 F10 F11 F12* F13* F14* F15
F16* F17 F18 F19 F20 F21 F22 F23* F24* F25* F26 F27* F28 F29 F30
F31* F32 F33* F34* F35* F36 F37* F38* F39* F40 F41 F42 F43 F44* F45
F46* F47* F48 F49 F50 F51 F52 F53 F54 F55 F56 F57 F58 F59 F60*
F61* F62 F63 F64 F65 F66 F67 F68 F69 F70 F71* F72* F73 F74 F75
F76* F77 F78 F79 F80 F81 F82* F83 F84 F85 F86* F87

TABLE 8 TRAINING & TESTING RESULTS USING OPTIMAL FEATURE SET.
(EMPIRICAL BAYESIAN CLASSIFIER)

MINIMUM DISTANCE CLASSIFIER

RESULT OF CLASSIFICATION

ID	SIZE	CONFUSION TABLE CLASS	1	2	3	4	RECOGNITION RATE
NOISE	24	1	19	5	0	0	79.17 %
S-INCL	16	2	6	10	0	0	62.50 %

OVERALL RECOGNITION RATE IS 72.50 %

30 FEATURES IN USE (MARKED WITH "*") --

F01* F02* F03* F04* F05 F06* F07 F08 F09 F10 F11 F12* F13* F14* F15
F16* F17 F18 F19 F20 F21 F22 F23* F24* F25* F26 F27* F28 F29 F30
F31* F32 F33* F34* F35* F36 F37* F38* F39* F40 F41 F42 F43 F44* F45
F46* F47* F48 F49 F50 F51 F52 F53 F54 F55 F56 F57 F58 F59 F60*
F61* F62 F63 F64 F65 F66 F67 F68 F69 F70 F71* F72* F73 F74 F75
F76* F77 F78 F79 F80 F81 F82* F83 F84 F85 F86* F87

MINIMUM DISTANCE CLASSIFIER

RESULT OF TESTING

ID	SIZE	CONFUSION TABLE CLASS	1	2	3	4	RECOGNITION RATE
NOISE	30	1	24	6	0	0	80.00 %
S-INCL	12	2	2	10	0	0	83.33 %

OVERALL RECOGNITION RATE IS 80.95 %

30 FEATURES IN USE (MARKED WITH "*") --

F01* F02* F03* F04* F05 F06* F07 F08 F09 F10 F11 F12* F13* F14* F15
F16* F17 F18 F19 F20 F21 F22 F23* F24* F25* F26 F27* F28 F29 F30
F31* F32 F33* F34* F35* F36 F37* F38* F39* F40 F41 F42 F43 F44* F45
F46* F47* F48 F49 F50 F51 F52 F53 F54 F55 F56 F57 F58 F59 F60*
F61* F62 F63 F64 F65 F66 F67 F68 F69 F70 F71* F7" F73 F74 F75
F76* F77 F78 F79 F80 F81 F82* F83 F84 F85 F86* F87

TABLE 9 TRAINING & TESTING RESULTS USING OPTIMAL FEATURE SET.
(MINIMIUM DISTANCE CLASSIFIER)

SUMMARY

Both system hardware and software performances have been optimized and demonstrated. Good recognition rates have been achieved and demonstration of control over the type of error to be assigned was achieved.

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APPENDIX I

RUN #1
TYPE OF INTENDED WELD : SMOOTH WELD

WELDING SETUP : CURRENT : 580-600 Amps
VOLTAGE : 32.33 V
SPEED : 24" per minute

REMARKS : 0.25" hole with copper tube filled with sulfur at 11.75" from transducer #1, which might produce cracks.

OBSERVATION : Centre line cracks at beginning and all through the weld

SLAM-4000 SETUP:

TRANSDUCER TYPE	: AET AC375	RESONANT FREQ. 375 KHz
PRE-AMPLIFIER	: GAIN = 60 DB	PASS BAND = 250 - 500 KHz
MAIN AMPLIFIER	: GAIN = 40 DB	PASS BAND = 250 - 500 KHz
DIGITIZER	: FREQ.= 5 MH	SIZE = 2048 POINTS 8 BITS
SOURCE LOCATOR	: TIME BASE = 8 MHz	DEAD TIME = 16 mSEC
TRIGGER LEVEL	: SETTING = 32	(~ 0.64 VOLT)

RUN #2
TYPE OF INTENDED WELD : SMOOTH WELD

WELDING SETUP : CURRENT : 600 Amps
VOLTAGE : 33 V
SPEED : 18" per minute

REMARKS : Same as above

OBSERVATION : Visible activities at 11.75" from transducer #1

SLAM-4000 SETUP:

TRANSDUCER TYPE	: AET AC375	RESONANT FREQ. 375 KHz
PRE-AMPLIFIER	: GAIN = 60 DB	PASS BAND = 250 - 500 KHz
MAIN AMPLIFIER	: GAIN = 30 DB	PASS BAND = 250 - 500 KHz
DIGITIZER	: FREQ.= 5 MH	SIZE = 2048 POINTS 8 BITS
SOURCE LOCATOR	: TIME BASE = 8 MHz	DEAD TIME = 16 mSEC
TRIGGER LEVEL	: SETTING = 32	(~ 0.64 VOLT)

RUN #3
TYPE OF INTENDED WELD : SMOOTH WELD

WELDING SETUP : CURRENT : 600 Amps
VOLTAGE : 33 V
SPEED : 18" per minute

REMARKS : Hard Pin (drill rod) sulfur behind at location #2 19" from transducer #1

OBSERVATION : No visible change in arc

SLAM-4000 SETUP:

TRANSDUCER TYPE	: AET AC375	RESONANT FREQ. 375 KHz
PRE-AMPLIFIER	: GAIN = 60 DB	PASS BAND = 250 - 500 KHz
MAIN AMPLIFIER	: GAIN = 20 DB	PASS BAND = 250 - 500 KHz
DIGITIZER	: FREQ.= 5 MH	SIZE = 2048 POINTS 8 BITS
SOURCE LOCATOR	: TIME BASE = 8 MHz	DEAD TIME = 16 mSEC
TRIGGER LEVEL	: SETTING = 32	(~ 0.64 VOLT)

RUN #4
TYPE OF INTENDED WELD : SMOOTH WELD

WELDING SETUP : CURRENT : 600 Amps
VOLTAGE : 33 V
SPEED : 18" per minute

REMARKS : Two soft drill rods with grease backing, pin #1 at 19" from transducer #1 and pin #2 at 34.5" from transducer #1

OBSERVATION : Post welding activity, might be slag cracking and some bump was produced at pin #1 location

SLAM-4000 SETUP:

TRANSDUCER TYPE	: AET AC375	RESONANT FREQ. 375 KHz
PRE-AMPLIFIER	: GAIN = 60 DB	PASS BAND = 250 - 500 KHz
MAIN AMPLIFIER	: GAIN = 20 DB	PASS BAND = 250 - 500 KHz
DIGITIZER	: FREQ.= 5 MH	SIZE = 2048 POINTS 8 BITS
SOURCE LOCATOR	: TIME BASE = 8 MHz	DEAD TIME = 16 mSEC
TRIGGER LEVEL	: SETTING = 32	(~ 0.64 VOLT)

RUN #5
TYPE OF INTENDED WELD : SULFUR INDUCED CRACK

WELDING SETUP : CURRENT : 600 Amps
VOLTAGE : 33 V
SPEED : 24" per minute

REMARKS : Sulfur was placed at locations 11" and 27" from transducer #1 each with a length of 2.5"

OBSERVATION : Visible cracks observed at each place, no other visible cracks, extra noise might be from arc instability

SLAM-4000 SETUP:

TRANSDUCER TYPE	: AET AC375	RESONANT FREQ. 375 KHz
PRE-AMPLIFIER	: GAIN = 60 DB	PASS BAND = 250 - 500 KHz
MAIN AMPLIFIER	: GAIN = 20 DB	PASS BAND = 250 - 500 KHz
DIGITIZER	: FREQ.= 5 MH	SIZE = 2048 POINTS 8 BITS
SOURCE LOCATOR	: TIME BASE = 8 MHz	DEAD TIME = 16 mSEC
TRIGGER LEVEL	: SETTING = 32	(~ 0.64 VOLT)

RUN #6
TYPE OF INTENDED WELD : SULFUR INDUCED CRACK

WELDING SETUP : CURRENT : 600 Amps
VOLTAGE : 33 V
SPEED : 24" per minute

REMARKS : More sulfur on the opposite side of pass 5.

OBSERVATION : At first sulfur run location arc stable, and at second sulfur run location erratic arc was observed.
Post weld activity much more active here.
Centre line cracks and transverse cracks observed at each sulfur regions.

SLAM-4000 SETUP:

TRANSDUCER TYPE	: AET AC375	RESONANT FREQ. 375 KHz
PRE-AMPLIFIER	: GAIN = 60 DB	PASS BAND = 250 - 500 KHz
MAIN AMPLIFIER	: GAIN = 20 DB	PASS BAND = 250 - 500 KHz
DIGITIZER	: FREQ.= 5 MH	SIZE = 2048 POINTS 8 BITS
SOURCE LOCATOR	: TIME BASE = 8 MHz	DEAD TIME = 16 mSEC
TRIGGER LEVEL	: SETTING = 32	(~ 0.64 VOLT)

RUN #7
TYPE OF INTENDED WELD : SMOOTH WELD

WELDING SETUP : CURRENT : 600 Amps
VOLTAGE : 33 V
SPEED : 24" per minute

REMARKS : First cover up bead over sulfur inclusion

OBSERVATION : Transverse crack at first sulfur run area, big longitudinal crack at second sulfur run area.

SLAM-4000 SETUP:

TRANSDUCER TYPE	: AET AC375	RESONANT FREQ. 375 KHz
PRE-AMPLIFIER	: GAIN = 60 DB	PASS BAND = 250 - 500 KHz
MAIN AMPLIFIER	: GAIN = 15 DB	PASS BAND = 250 - 500 KHz
DIGITIZER	: FREQ.= 5 MH	SIZE = 2048 POINTS 8 BITS
SOURCE LOCATOR	: TIME BASE = 8 MHz	DEAD TIME = 16 mSEC
TRIGGER LEVEL	: SETTING = 32	(~ 0.64 VOLT)

RUN #8
TYPE OF INTENDED WELD : SMOOTH WELD

WELDING SETUP : CURRENT : 600 Amps
VOLTAGE : 33 V
SPEED : 24" per minute

REMARKS : Second cover up bead over sulfur inclusion

OBSERVATION : Transverse cracks and centre line cracks observed at each sulfur inclusion areas.

SLAM-4000 SETUP:

TRANSDUCER TYPE	: AET AC375	RESONANT FREQ. 375 KHz
PRE-AMPLIFIER	: GAIN = 60 DB	PASS BAND = 250 - 500 KHz
MAIN AMPLIFIER	: GAIN = 10 DB	PASS BAND = 250 - 500 KHz
DIGITIZER	: FREQ.= 5 MH	SIZE = 2048 POINTS 8 BITS
SOURCE LOCATOR	: TIME BASE = 8 MHz	DEAD TIME = 16 mSEC
TRIGGER LEVEL	: SETTING = 32	(~ 0.64 VOLT)

RUN #9
TYPE OF INTENDED WELD : SMOOTH WELD

WELDING SETUP : CURRENT : 600 Amps
VOLTAGE : 33 V
SPEED : 24" per minute

REMARKS : Third cover up bead over sulfur inclusion

OBSERVATION : Large transverse cracks and longitudinal cracks observed at each sulfur inclusion positions.

SLAM-4000 SETUP:

TRANSDUCER TYPE	: AET AC375	RESONANT FREQ. 375 KHz
PRE-AMPLIFIER	: GAIN = 60 DB	PASS BAND = 250 - 500 KHz
MAIN AMPLIFIER	: GAIN = 15 DB	PASS BAND = 250 - 500 KHz
DIGITIZER	: FREQ.= 5 MH	SIZE = 2048 POINTS 8 BITS
SOURCE LOCATOR	: TIME BASE = 8 MHz	DEAD TIME = 16 mSEC
TRIGGER LEVEL	: SETTING = 32	(~ 0.64 VOLT)

RUN #10
TYPE OF INTENDED WELD : SMOOTH WELD

WELDING SETUP : CURRENT : 600 Amps
VOLTAGE : 33 V
SPEED : 24" per minute

REMARKS : Fourth cover up bead over sulfur inclusion.
Crack areas were dug out and filled before welding.

OBSERVATION : Lacking of welding at old sulfur inclusion areas.

SLAM-4000 SETUP:

TRANSDUCER TYPE	: AET AC375	RESONANT FREQ. 375 KHz
PRE-AMPLIFIER	: GAIN = 60 DB	PASS BAND = 250 - 500 KHz
MAIN AMPLIFIER	: GAIN = 15 DB	PASS BAND = 250 - 500 KHz
DIGITIZER	: FREQ.= 5 MH	SIZE = 2048 POINTS 8 BITS
SOURCE LOCATOR	: TIME BASE = 8 MHz	DEAD TIME = 16 mSEC
TRIGGER LEVEL	: SETTING = 32	(~ 0.64 VOLT)

RUN #11
TYPE OF INTENDED WELD : SMOOTH WELD

WELDING SETUP : CURRENT : 600 Amps
VOLTAGE : 33 V
SPEED : 24" per minute

REMARKS : Drill rod with sulfur behind At 5.5" from transducer #1.

OBSERVATION: Slag entrapment effect was attempted at the region from 23.5" to 26.5" from transducer #1.

SLAM-4000 SETUP:

TRANSDUCER TYPE	: AET AC375	RESONANT FREQ. 375 KHz
PRE-AMPLIFIER	: GAIN = 60 DB	PASS BAND = 250 - 500 KHz
MAIN AMPLIFIER	: GAIN = 10 DB	PASS BAND = 250 - 500 KHz
DIGITIZER	: FREQ.= 5 MH	SIZE = 2048 POINTS 8 BITS
SOURCE LOCATOR	: TIME BASE = 8 MHz	DEAD TIME = 16 mSEC
TRIGGER LEVEL	: SETTING = 32	(~ 0.64 VOLT)

RUN #12
TYPE OF INTENDED WELD : SMOOTH WELD

WELDING SETUP : CURRENT : 600 Amps
VOLTAGE : 33 V
SPEED : 22.5" per minute

REMARKS : Copper were placed at 18" and 31.5" from transducer #1. A 1.75" long steel wire was place at 2.75" from transducer #1.

OBSERVATION : No crack observed.

SLAM-4000 SETUP:

TRANSDUCER TYPE	: AET AC375	RESONANT FREQ. 375 KHz
PRE-AMPLIFIER	: GAIN = 60 DB	PASS BAND = 250 - 500 KHz
MAIN AMPLIFIER	: GAIN = 10 DB	PASS BAND = 250 - 500 KHz
DIGITIZER	: FREQ.= 5 MH	SIZE = 2048 POINTS 8 BITS
SOURCE LOCATOR	: TIME BASE = 8 MHz	DEAD TIME = 16 mSEC
TRIGGER LEVEL	: SETTING = 32	(~ 0.64 VOLT)

RUN #13
TYPE OF INTENDED WELD : ARC INSTABILITY

WELDING SETUP : CURRENT : 600 Amps
VOLTAGE : 33 V
SPEED : 22.5" per minute

REMARKS : Test effect on arc instability.

OBSERVATION : No visible effect except lack of fussion.

SLAM-4000 SETUP:

TRANSDUCER TYPE	: AET AC375	RESONANT FREQ. 375 KHz
PRE-AMPLIFIER	: GAIN = 60 DB	PASS BAND = 250 - 500 KHz
MAIN AMPLIFIER	: GAIN = 10 DB	PASS BAND = 250 - 500 KHz
DIGITIZER	: FREQ.= 5 MH	SIZE = 2048 POINTS 8 BITS
SOURCE LOCATOR	: TIME BASE = 8 MHz	DEAD TIME = 16 mSEC
TRIGGER LEVEL	: SETTING = 32	(~ 0.64 VOLT)

RUN #14
TYPE OF INTENDED WELD : ARC INSTABILITY

WELDING SETUP : CURRENT : 600 Amps
VOLTAGE : 33 V
SPEED : 22.5" per minute

REMARKS : Test arc instability effect.

OBSERVATION : No visible effect observed.

SLAM-4000 SETUP:

TRANSDUCER TYPE	: AET AC375	RESONANT FREQ. 375 KHz
PRE-AMPLIFIER	: GAIN = 60 DB	PASS BAND = 250 - 500 KHz
MAIN AMPLIFIER	: GAIN = 10 DB	PASS BAND = 250 - 500 KHz
DIGITIZER	: FREQ.= 5 MH	SIZE = 2048 POINTS 8 BITS
SOURCE LOCATOR	: TIME BASE = 8 MHz	DEAD TIME = 16 mSEC
TRIGGER LEVEL	: SETTING = 32	(~ 0.64 VOLT)

RUN #15 AND #16
TYPE OF INTENDED WELD : CHIPPING AND WIRE BRUSHING

WELDING SETUP : CURRENT : 0 Amps
VOLTAGE : 0 V
SPEED : 0" per minute

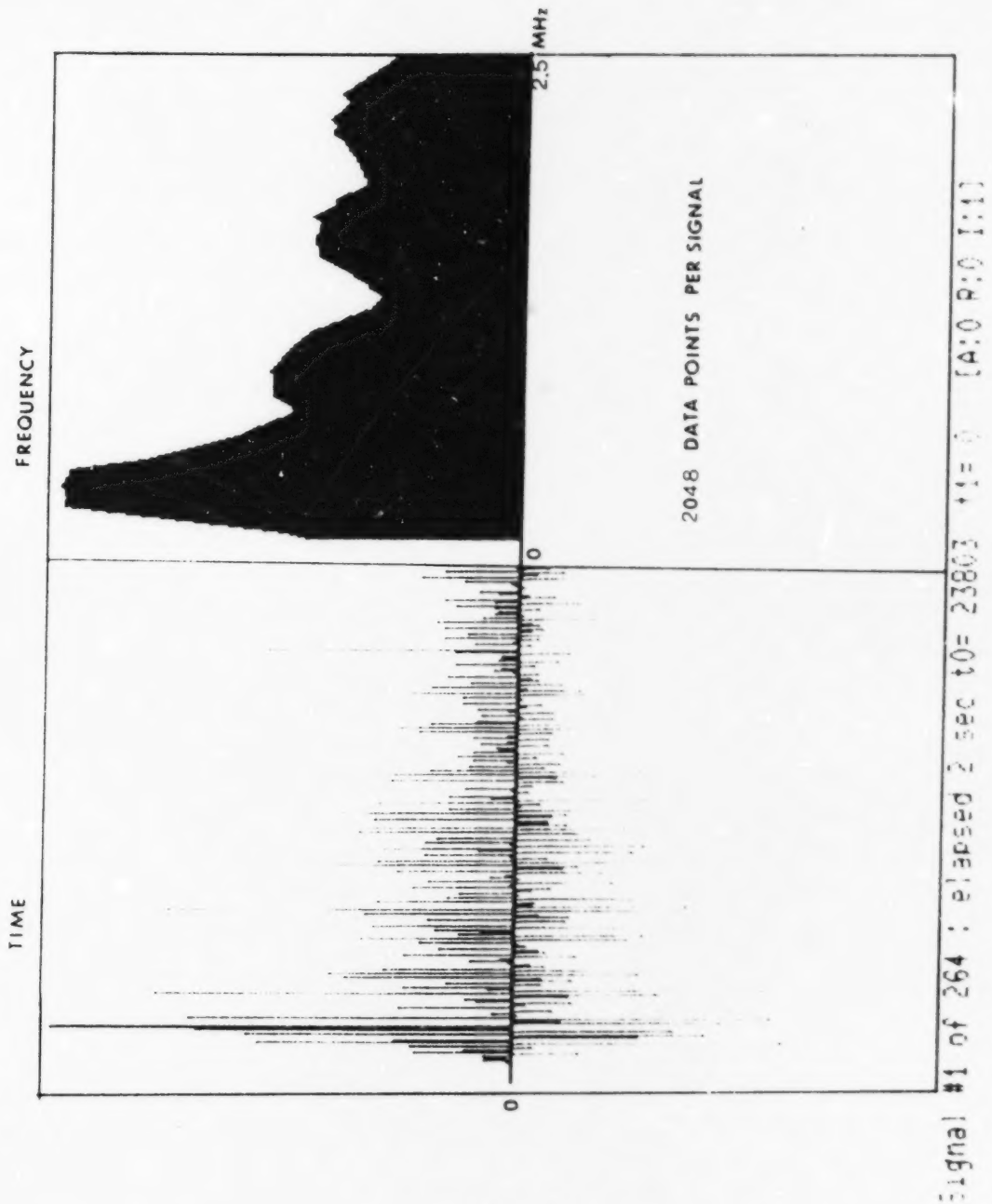
REMARKS : Noise signal associated with chipping and wire brushing signal were gathered for test of the noise immunity of the system to the normal welding operation noise generated by both machine and human operators.

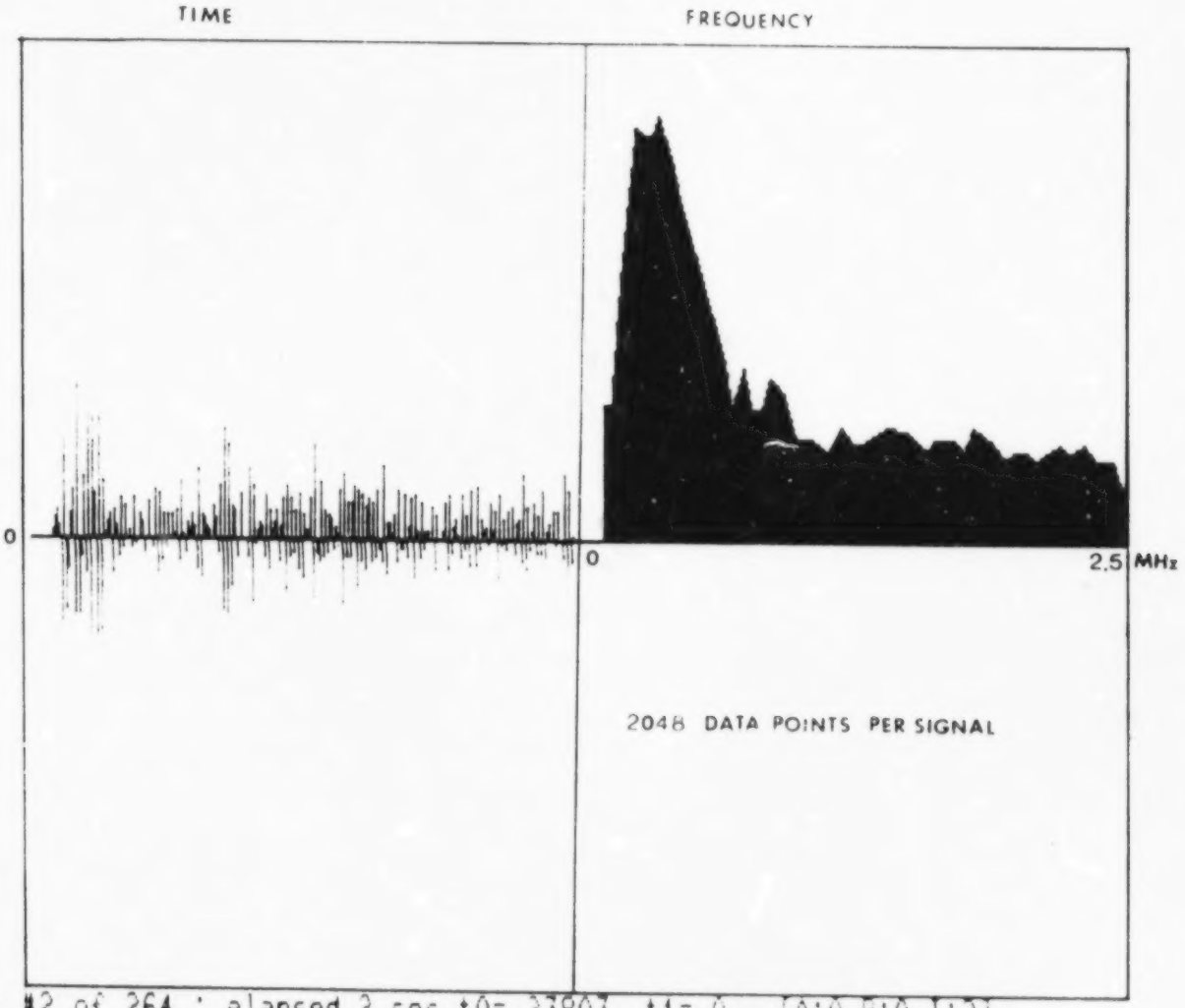
OBSERVATION: The system is relatively insensitive to these two type of noise. The operator has to hit really hard in order to trigger the system.

SLAM-4000 SETUP:

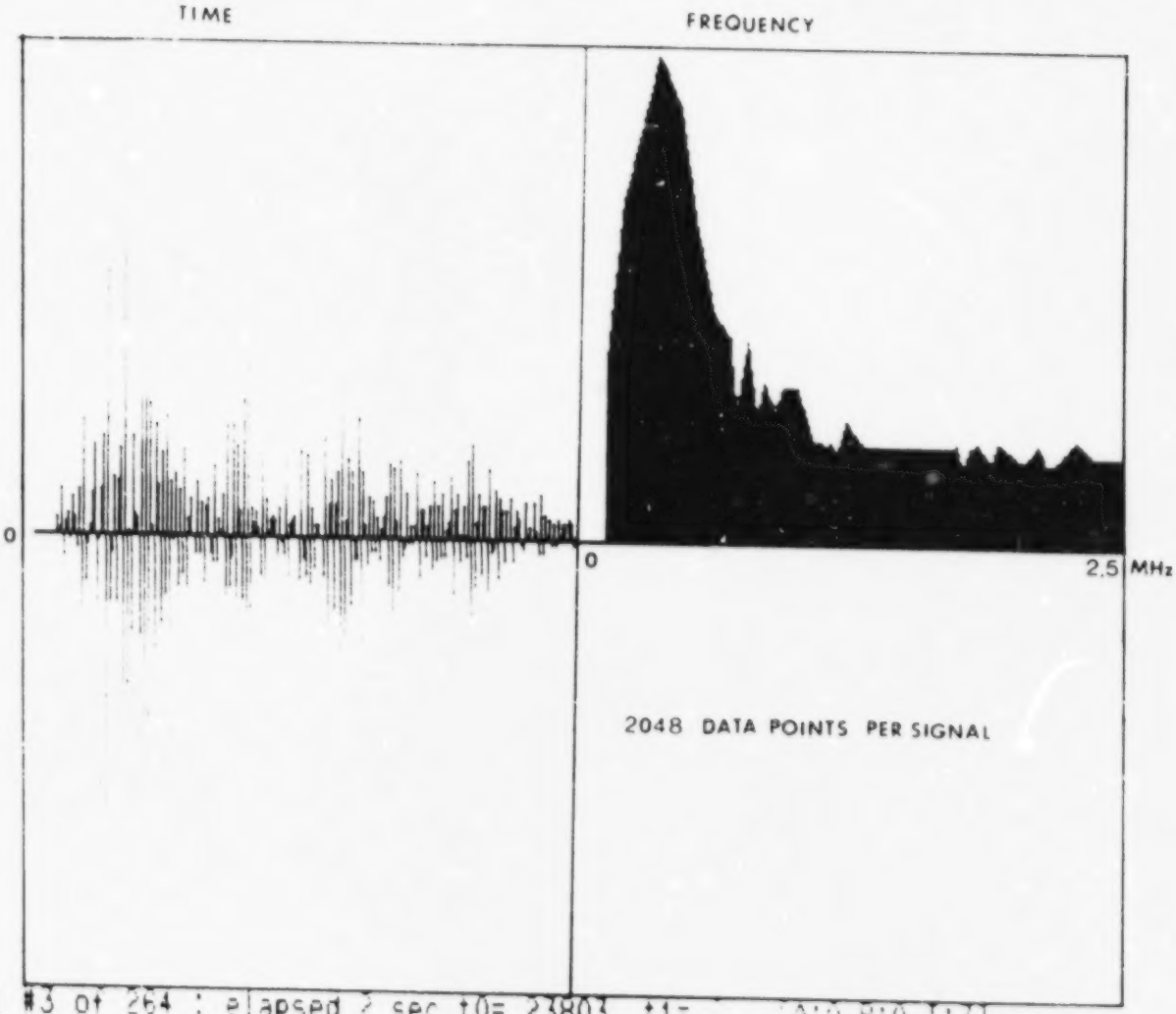
TRANSDUCER TYPE	: AET AC375	RESONANT FREQ. 375 KHz
PRE-AMPLIFIER	: GAIN = 60 DB	PASS BAND = 250 - 500 KHz
MAIN AMPLIFIER	: GAIN = 10 DB	PASS BAND = 250 - 500 KHz
DIGITIZER	: FREQ.= 5 MH	SIZE = 2048 POINTS 8 BITS
SOURCE LOCATOR	: TIME BASE = 8 MHz	DEAD TIME = 16 mSEC
TRIGGER LEVEL	: SETTING = 32	(~ 0.64 VOLT)

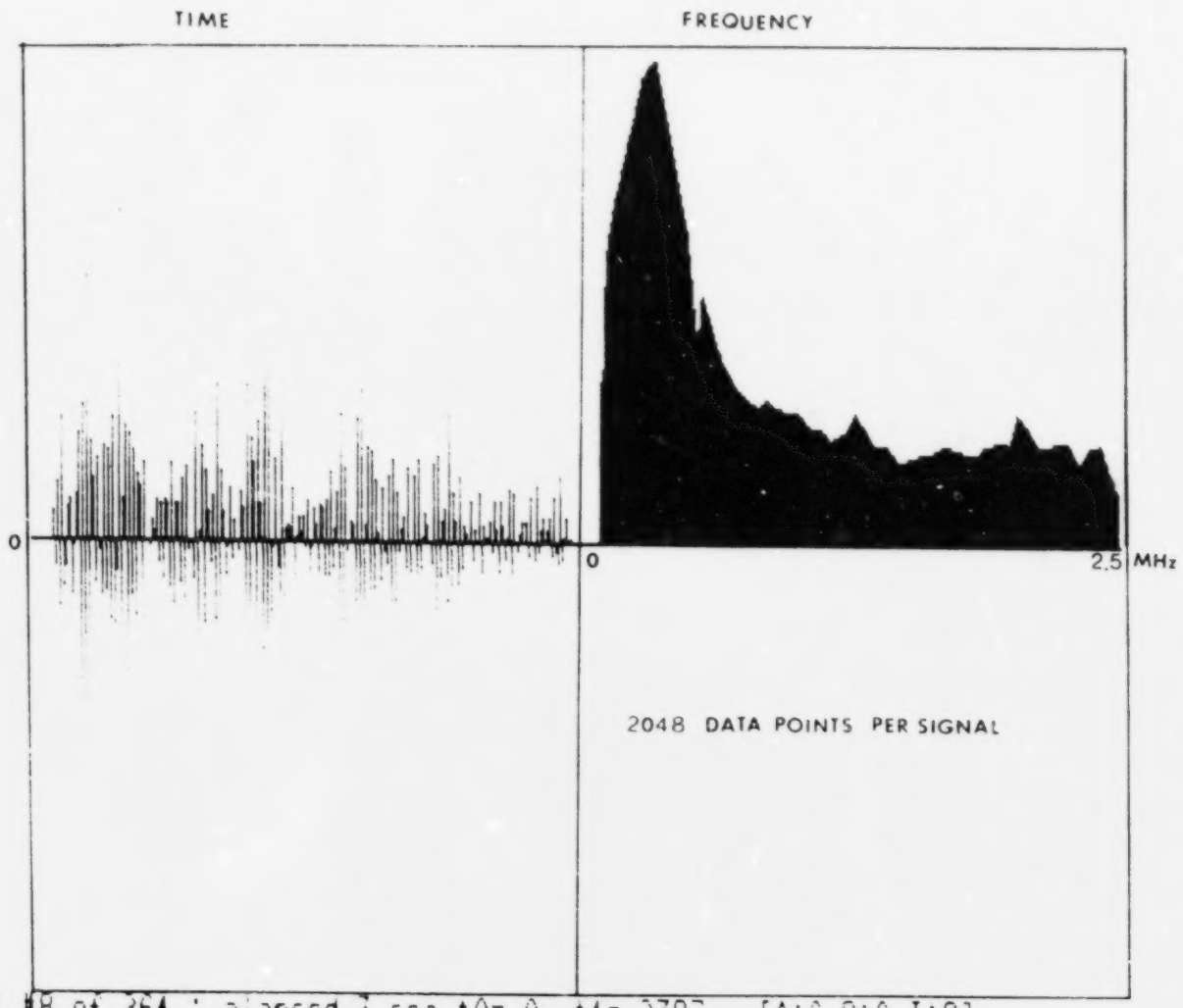
APPENDIX II

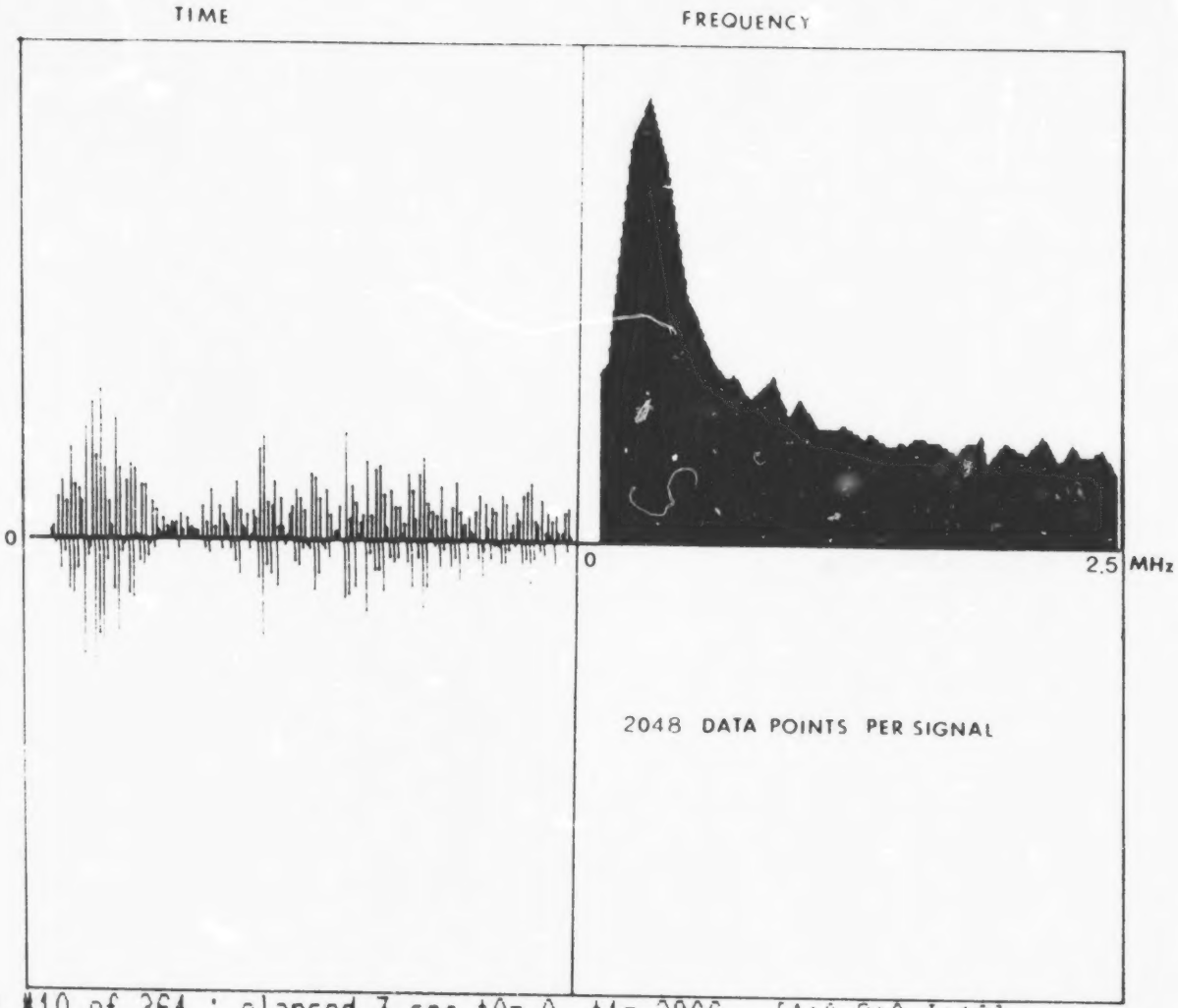

FREQUENCY
TIME
2.5 MHz
0
0
2048 DATA POINTS PER SIGNAL
Signal #1 of 264 : elapsed 2 sec t0= 23803 +1= 0 [A:0 R:0 I:1]

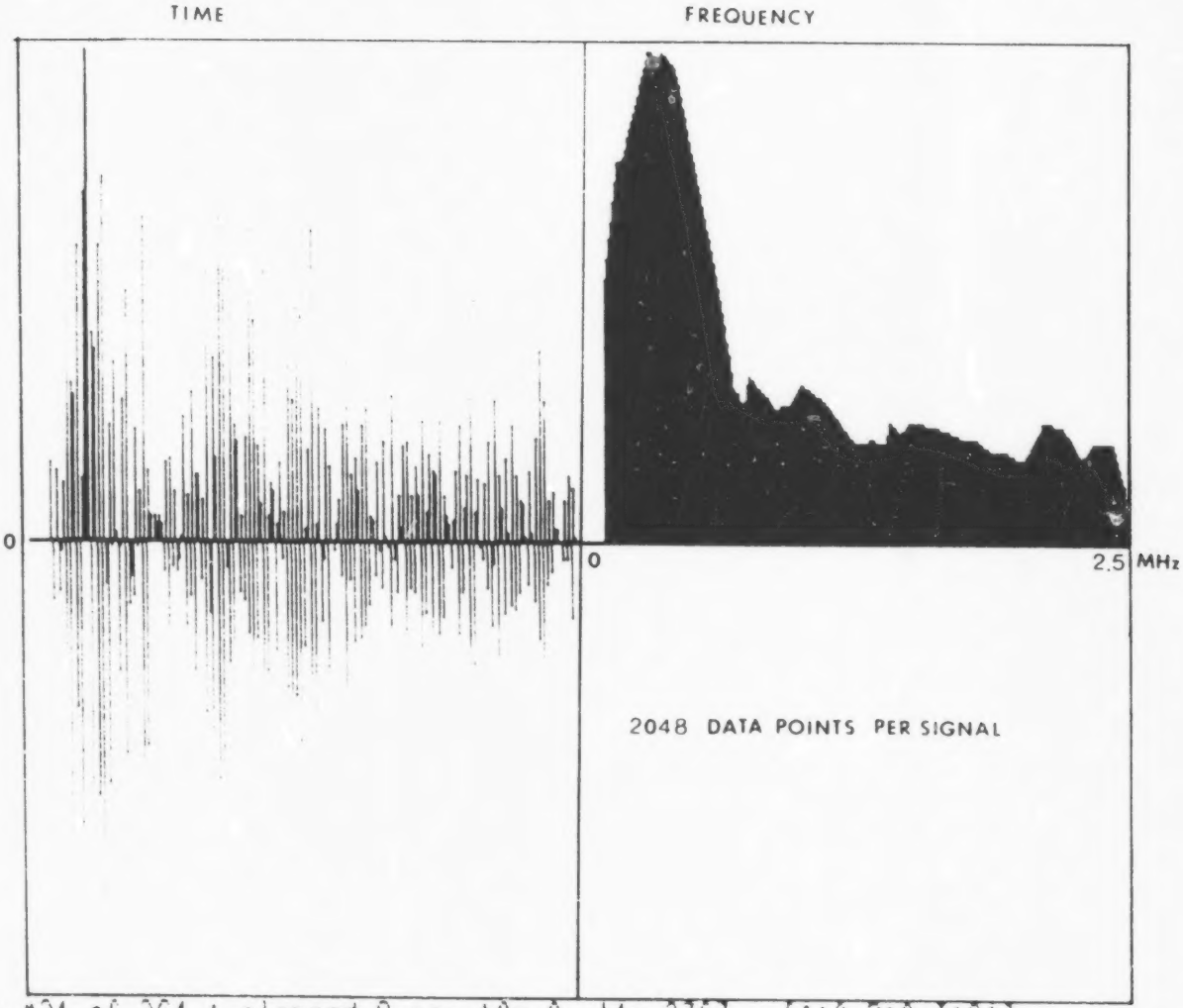


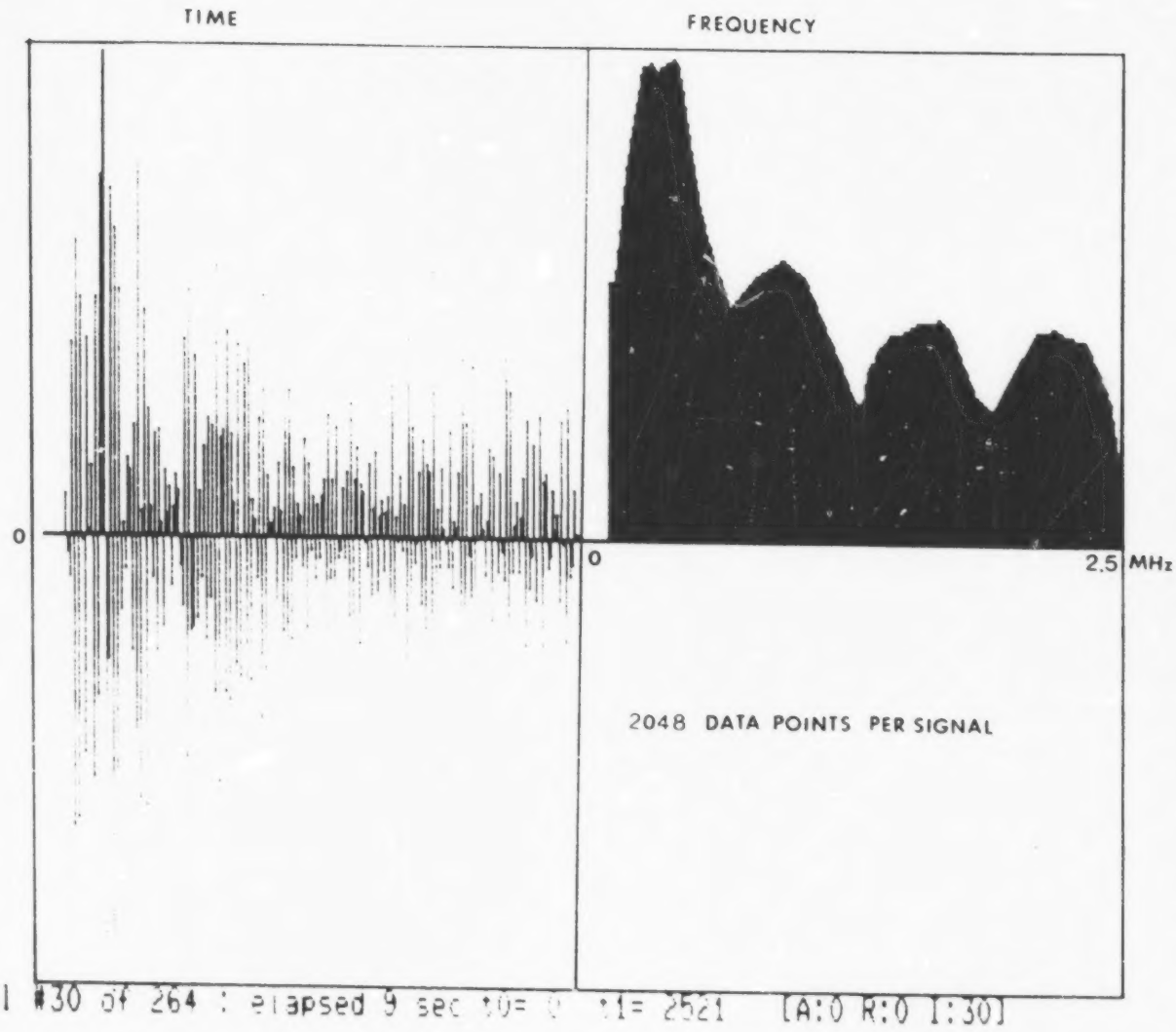
Signal #2 of 264 : elapsed 2 sec t0= 23803 t1= 0 (A:0 F:0 I:2)_

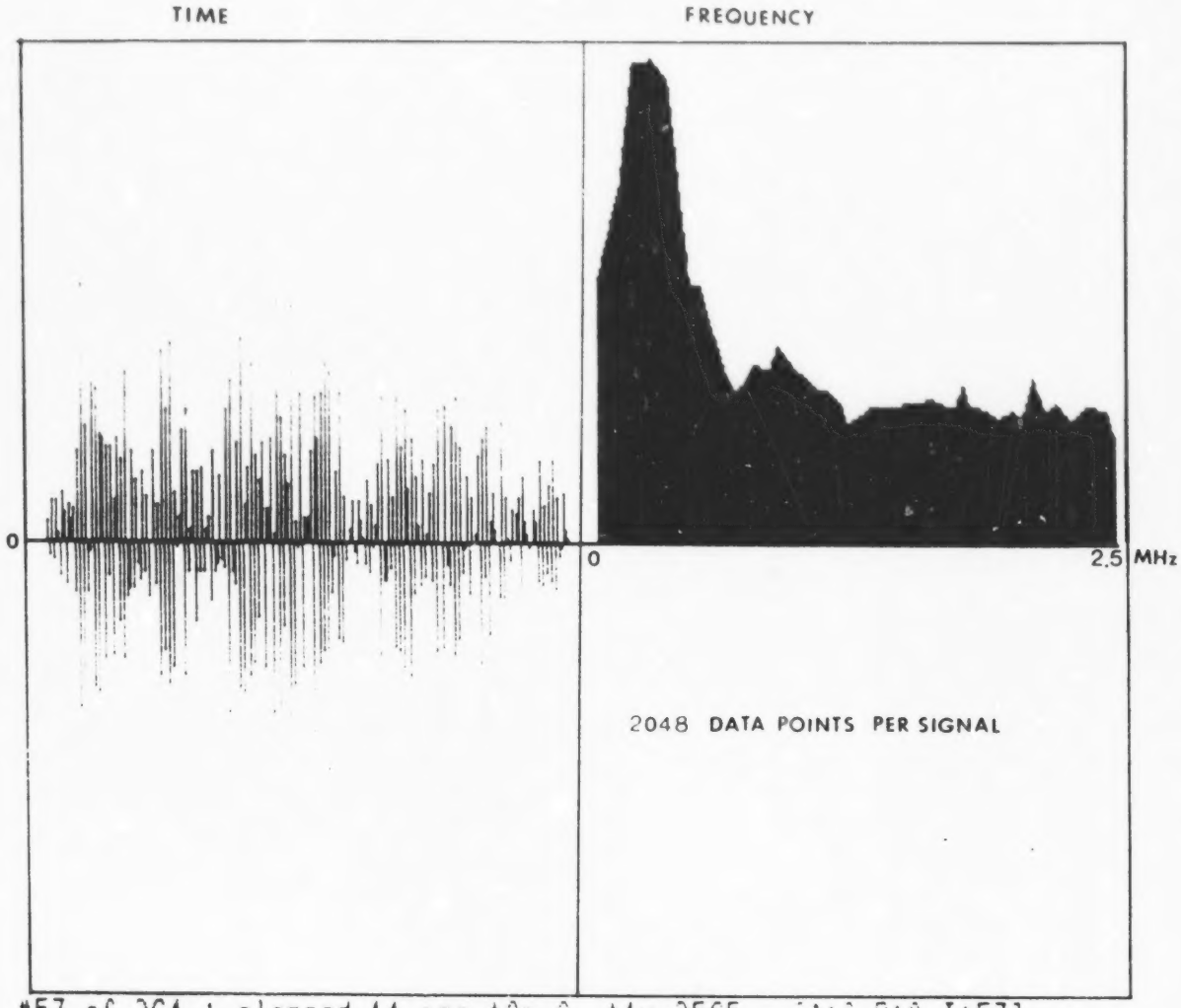

TIME
FREQUENCY
0
0
2.5 MHz
2048 DATA POINTS PER SIGNAL
Signal #3 of 264 : elapsed 2 sec t0= 23803 t1=

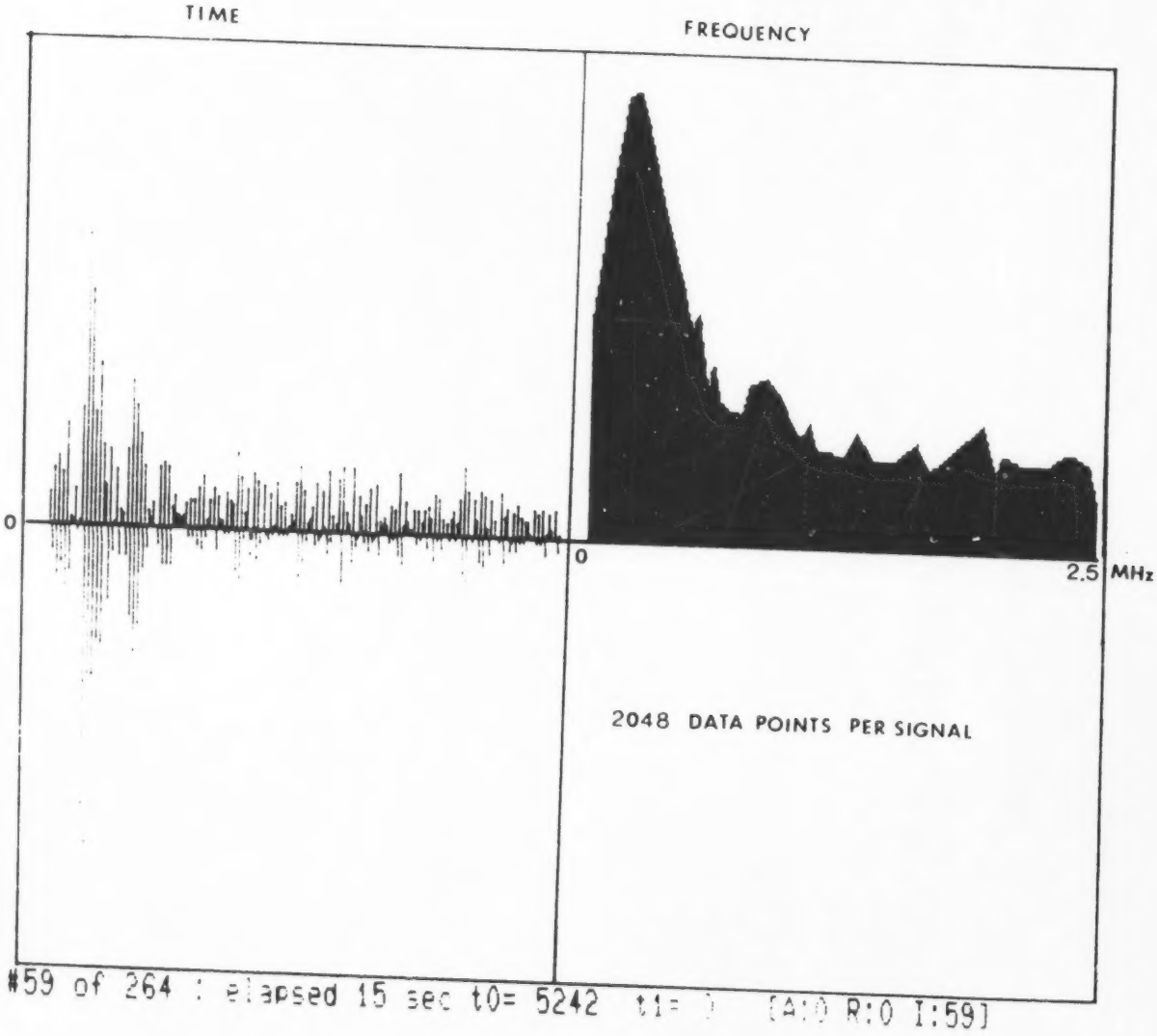

TIME
FREQUENCY
0
0
2.5 MHz
2048 DATA POINTS PER SIGNAL
Signal #8 of 264 : elapsed 3 sec t0= 0 t1= 2387 [A:0 R:0 I:8]

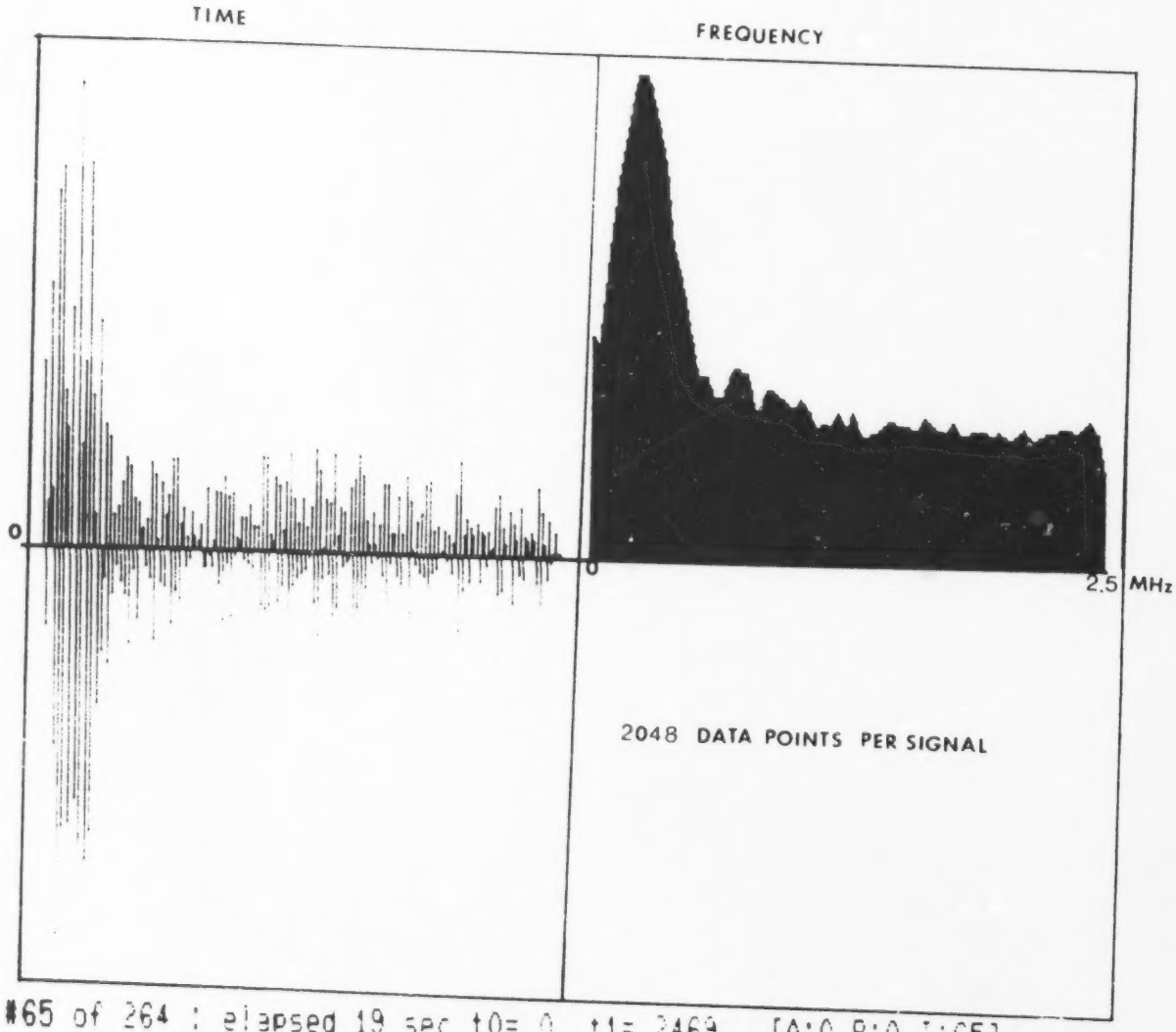

TIME
FREQUENCY
0
0
2.5 MHz
2048 DATA POINTS PER SIGNAL
Signal #10 of 264 : elapsed 3 sec t0= 0 t1= 2906 [A:0 R:0 I:10]


TIME
FREQUENCY
0
0
2.5 MHz
2048 DATA POINTS PER SIGNAL
.arsal #21 of 264 : elapsed 8 sec t0= 0 t1= 2363 [A:0 R:0 I:21]_

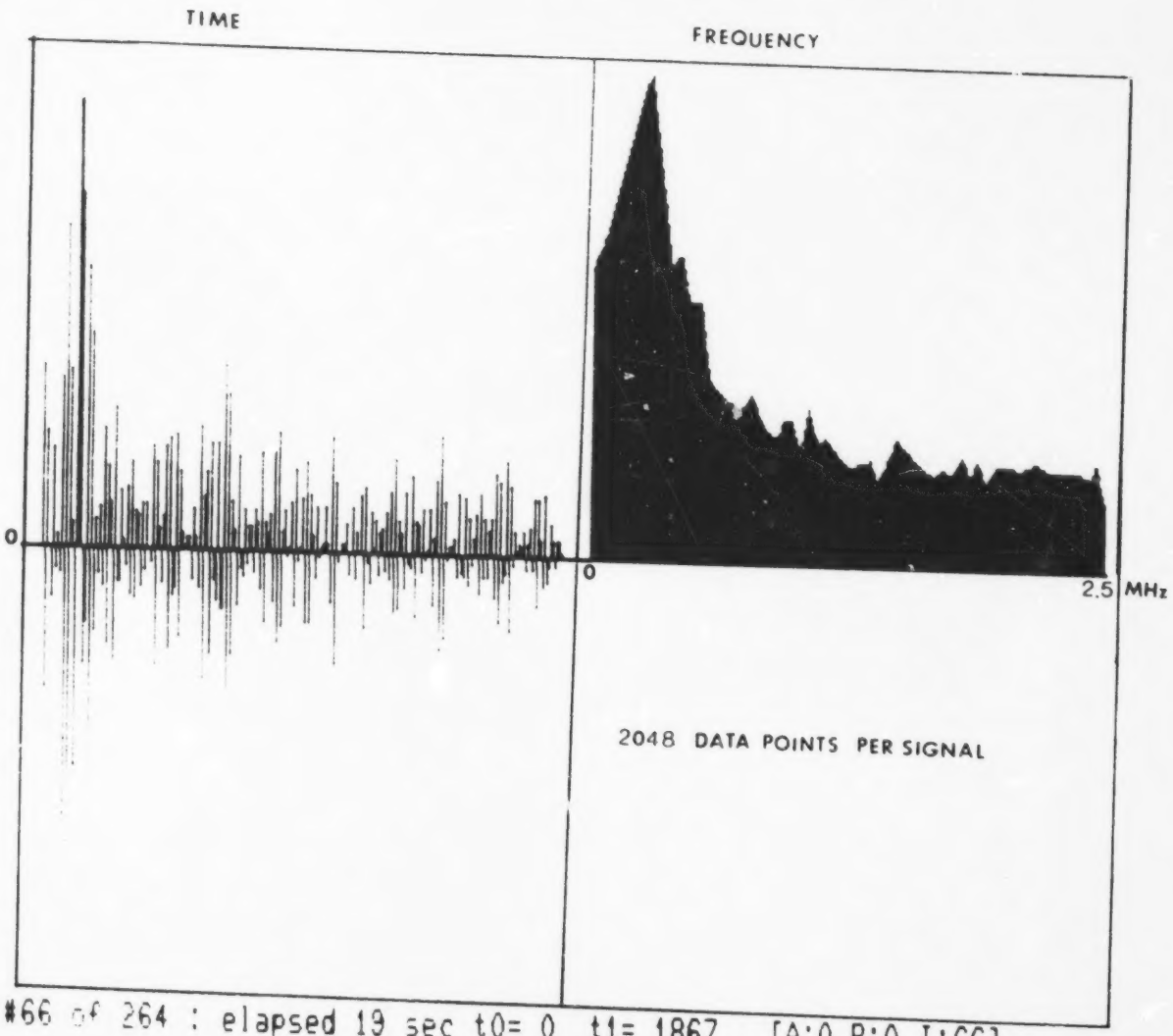

TIME
FREQUENCY
0
0
2.5 MHz
2048 DATA POINTS PER SIGNAL
Signal #30 of 264 : elapsed 9 sec t0= 0 t1= 2521 [A:0 R:0 I:30]


TIME
FREQUENCY
0
0
2.5 MHz
2048 DATA POINTS PER SIGNAL
Signal #53 of 264 : elapsed 14 sec t0= 0 t1= 2565 [A:] R:0 I:53]

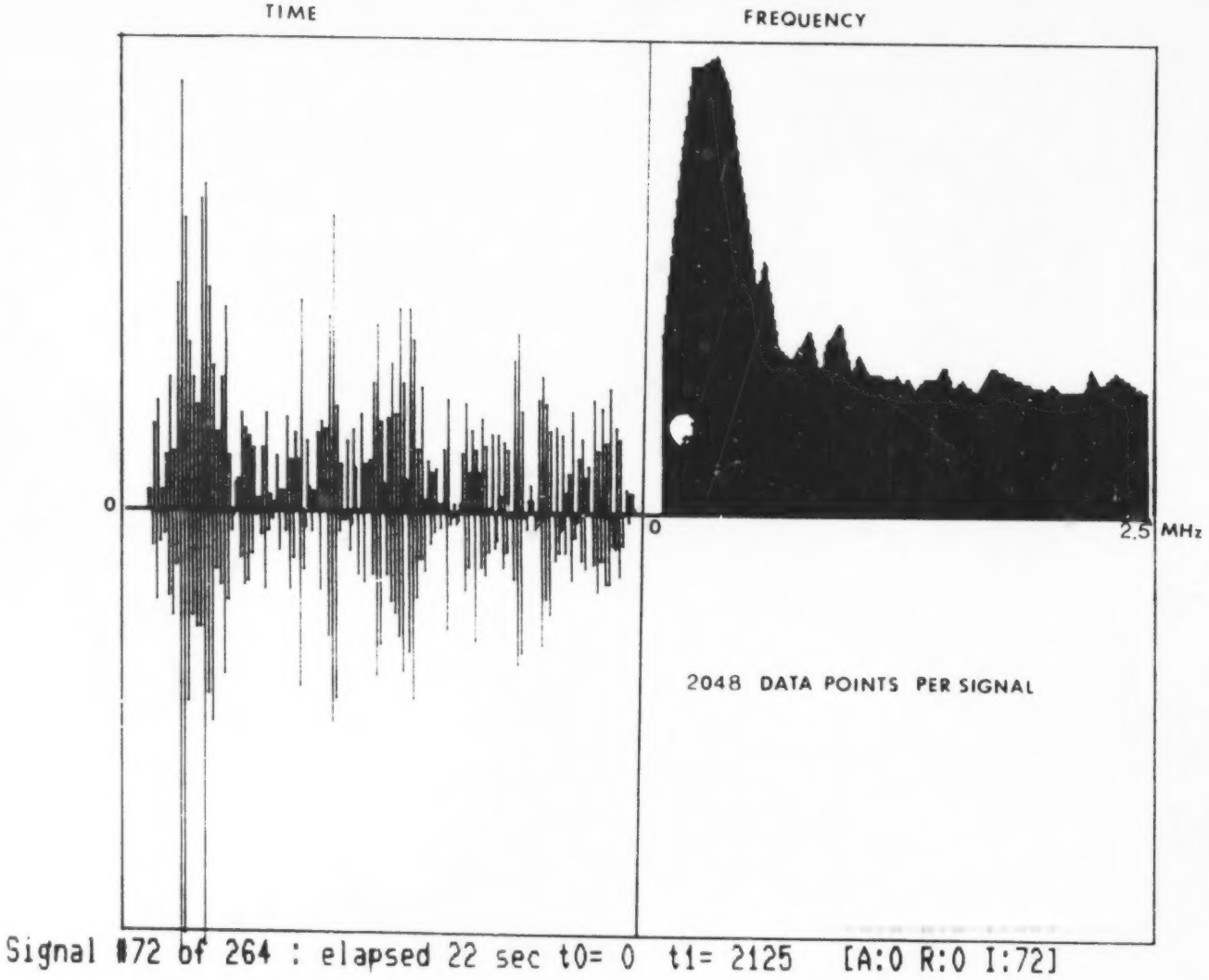

TIME
FREQUENCY
0
0
2.5 MHz
2048 DATA POINTS PER SIGNAL
Signal #59 of 264 : elapsed 15 sec t0= 5242 t1=) [A:0 R:0 I:59]

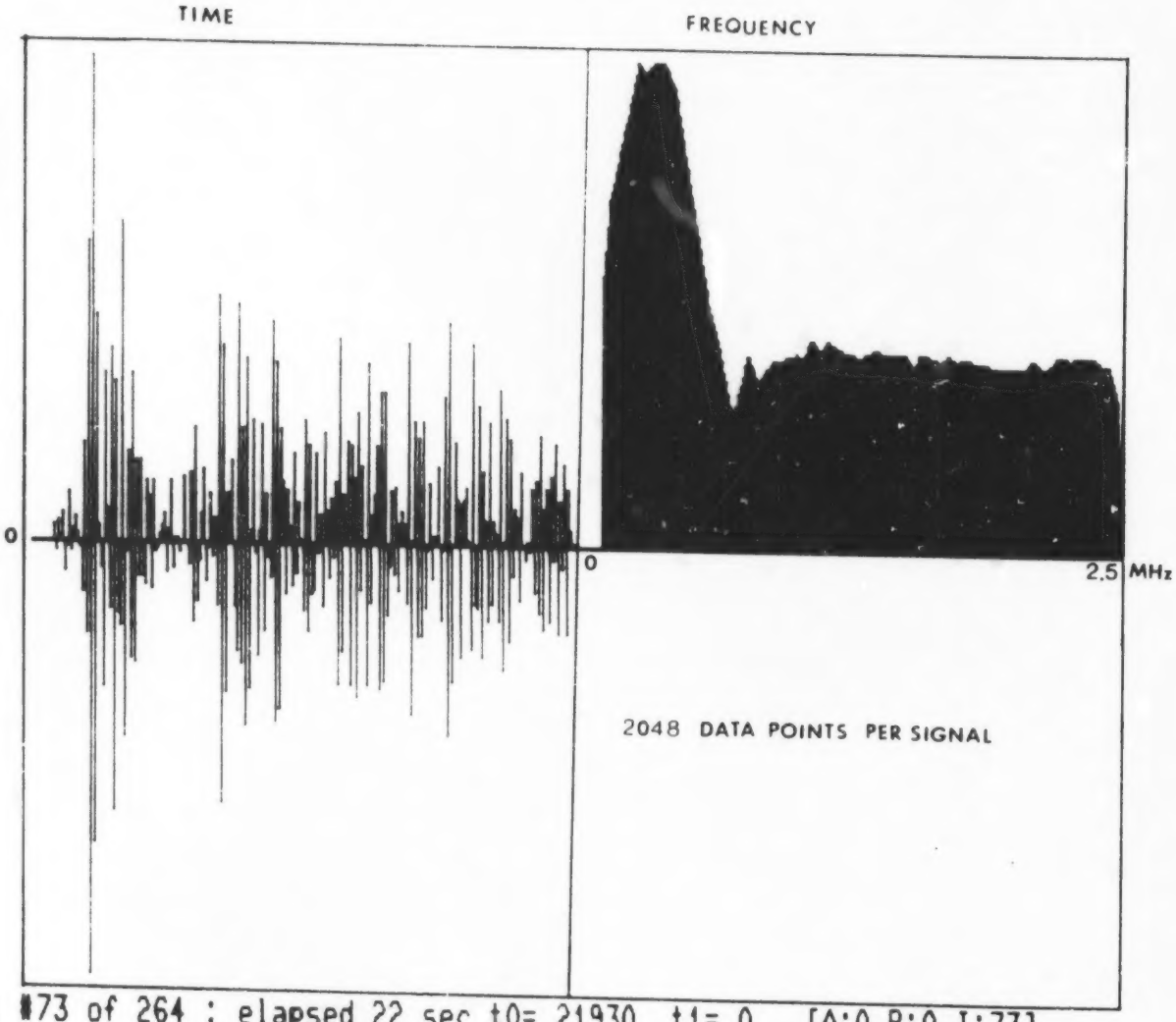


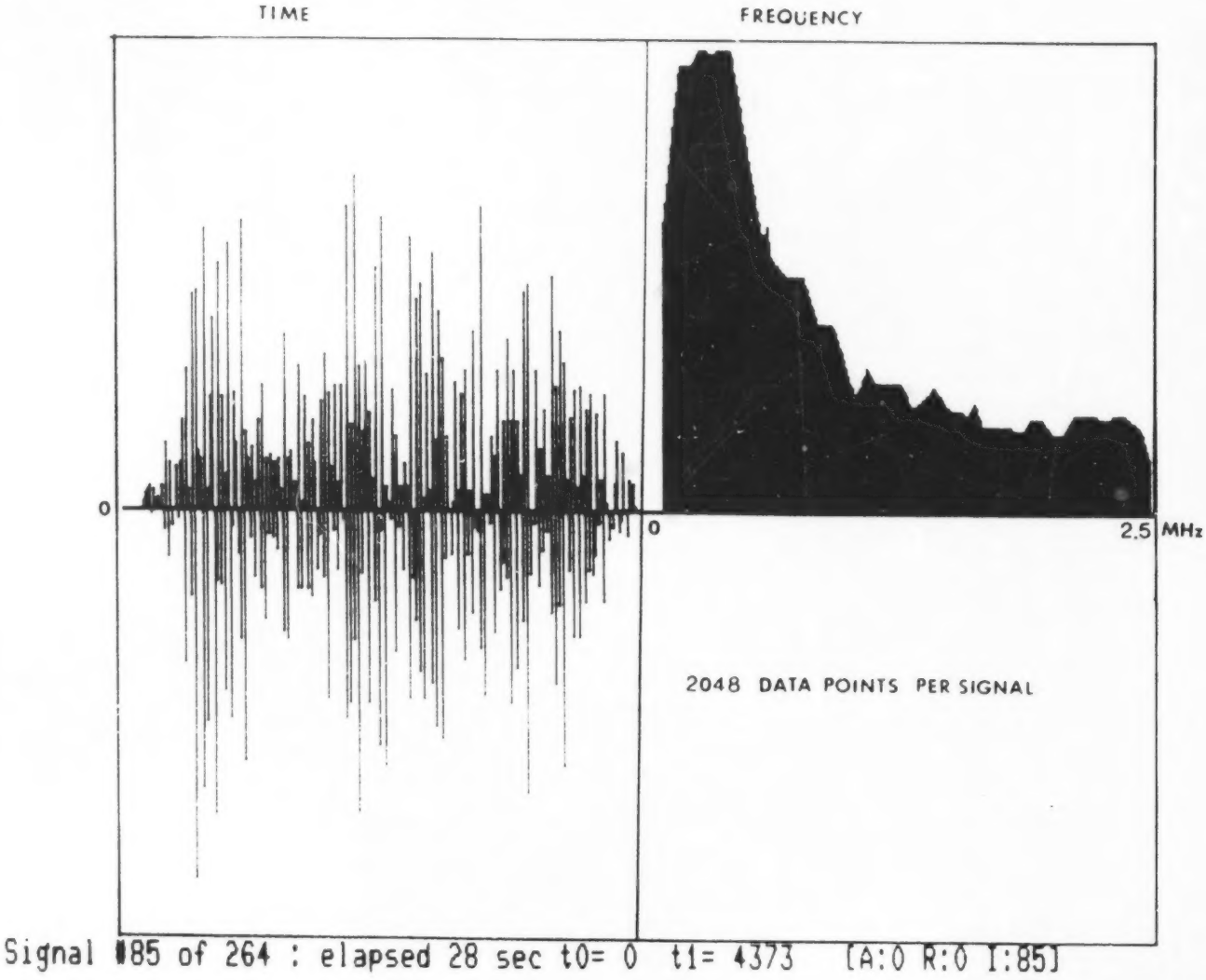
Signal #65 of 264 : elapsed 19 sec t0= 0 t1= 2469 [A:0 R:0 I:65]

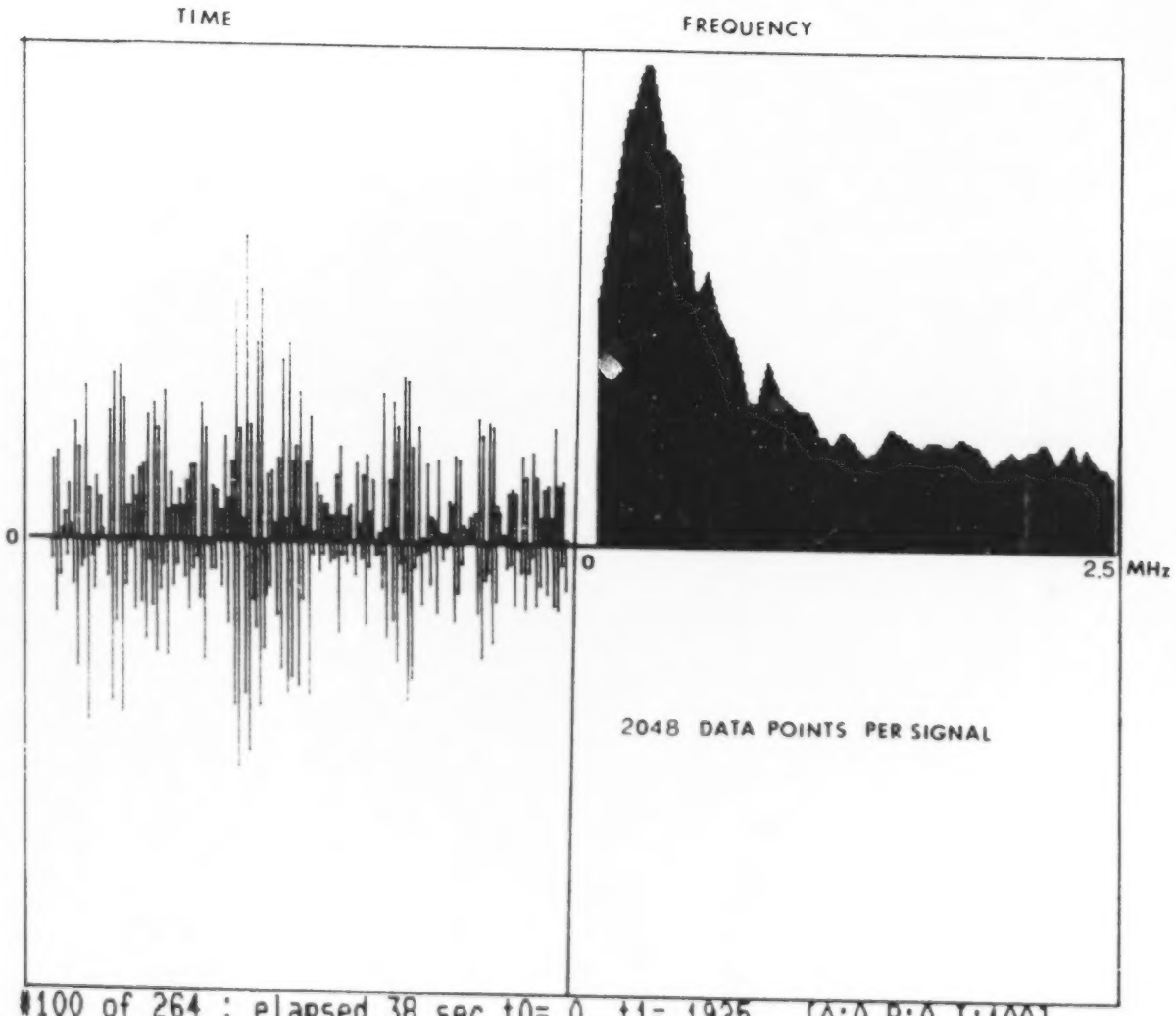


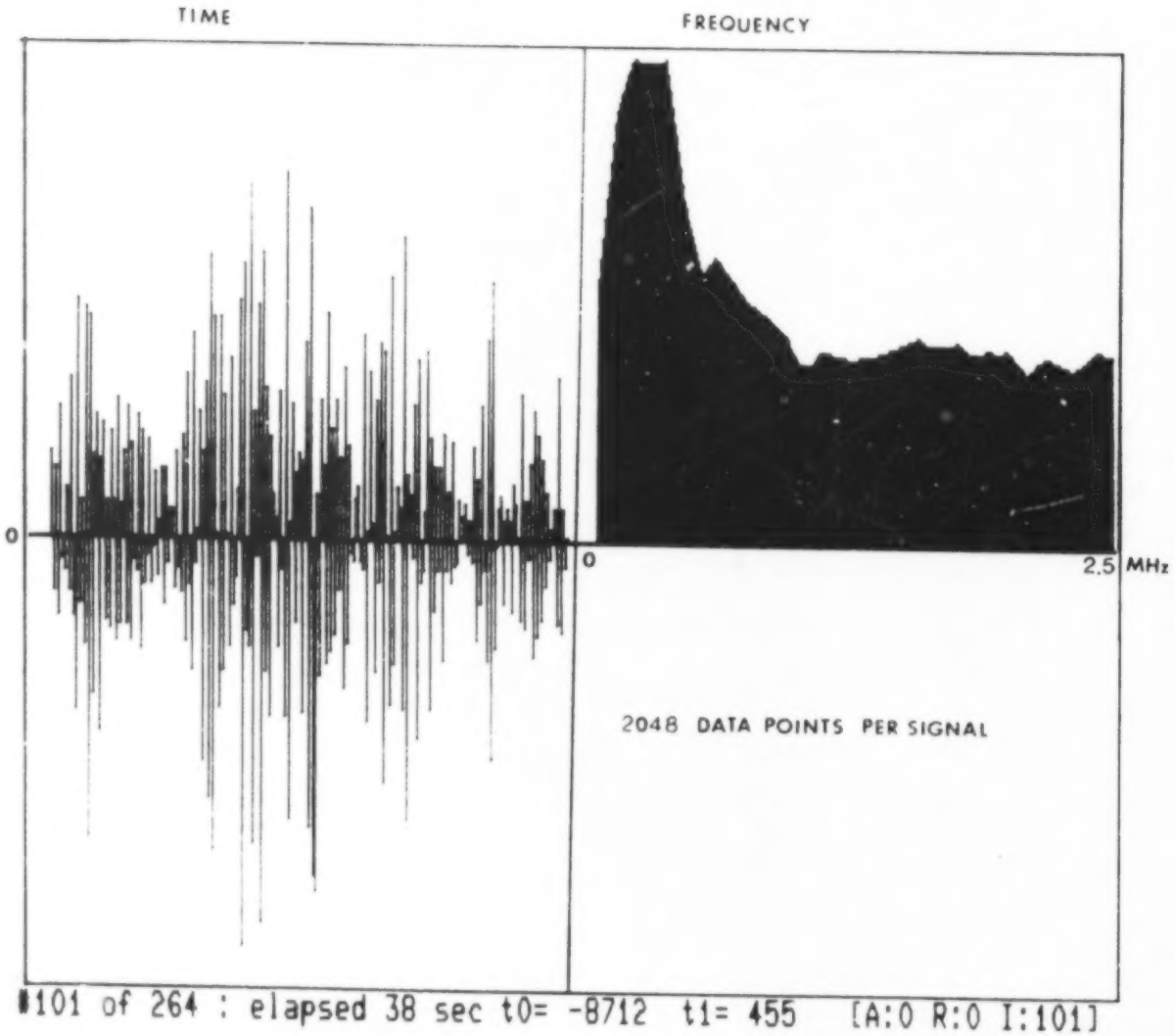
Signal #66 of 264 : elapsed 19 sec t0= 0 t1= 1867 [A:0 R:0 I:66]

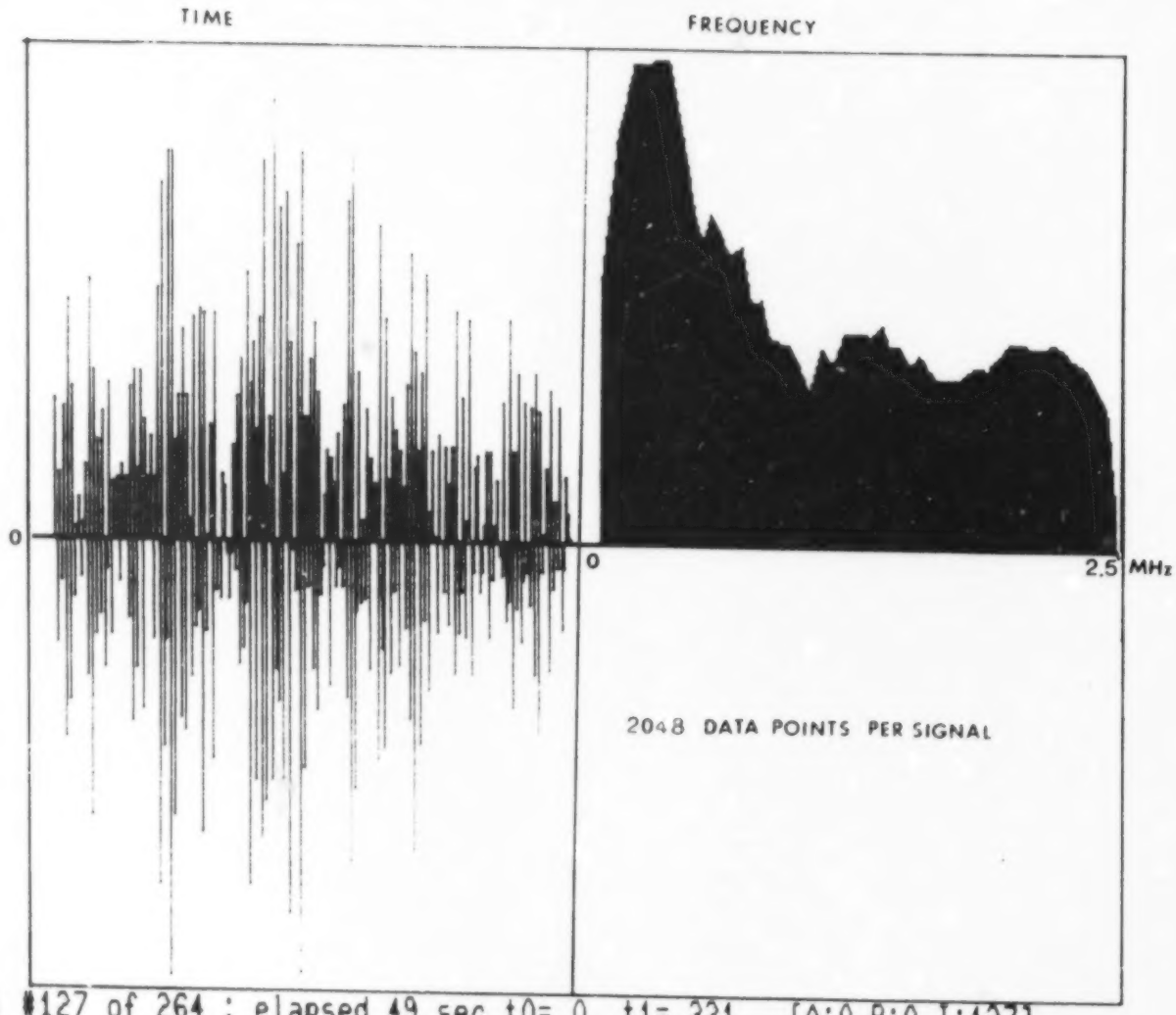

TIME
FREQUENCY
0
0
2.5 MHz
2048 DATA POINTS PER SIGNAL
Signal #72 of 264 : elapsed 22 sec t0= 0 t1= 2125 [A:0 R:0 I:72]

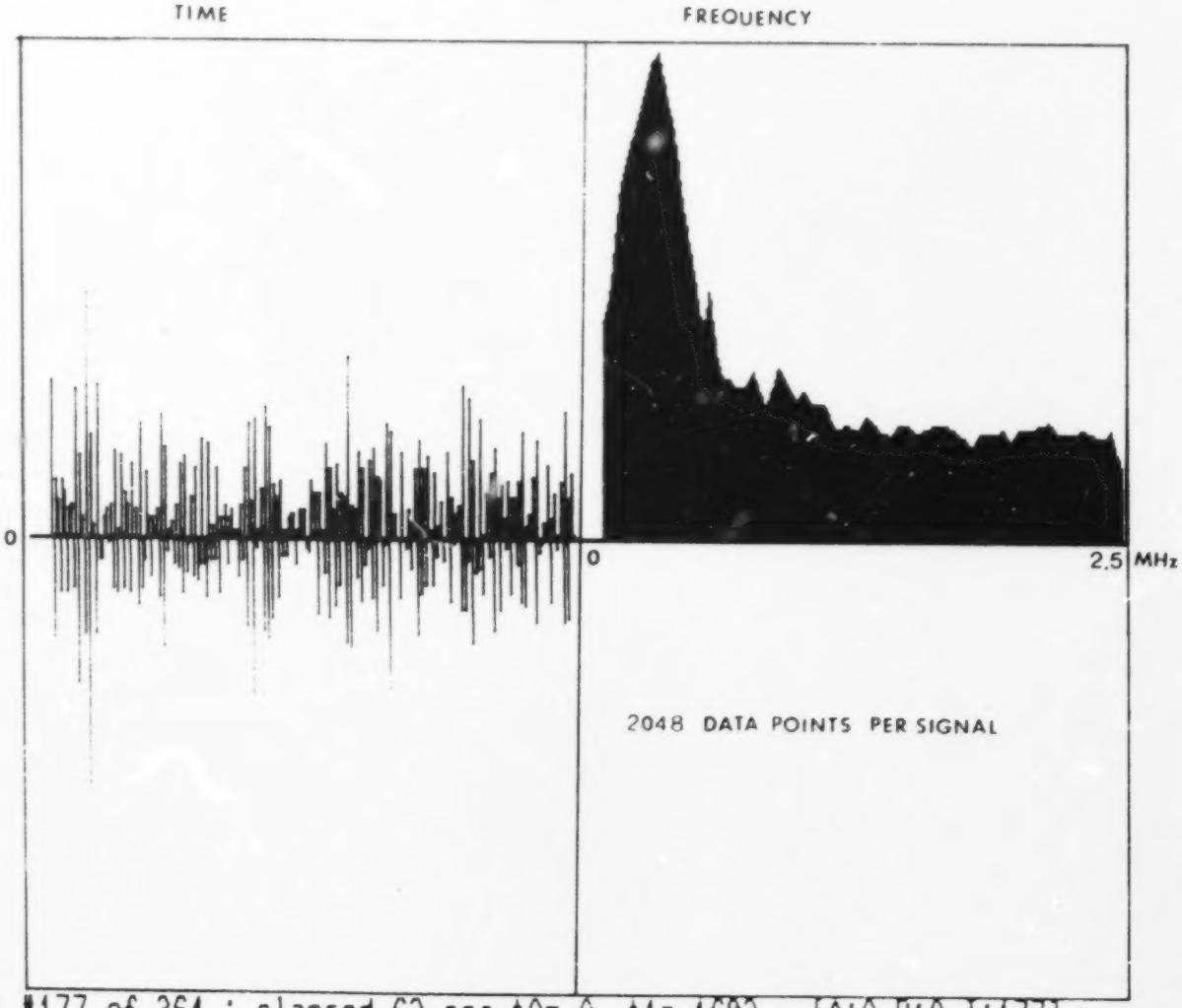

TIME
FREQUENCY
0
0
2.5 MHz
2048 DATA POINTS PER SIGNAL
Signal #73 of 264 : elapsed 22 sec t0= 21930 t1= 0 [A:0 R:0 I:73]


TIME
FREQUENCY
0
0
2.5 MHz
2048 DATA POINTS PER SIGNAL
Signal #85 of 264 : elapsed 28 sec t0= 0 t1= 4373 [A:0 R:0 I:85]

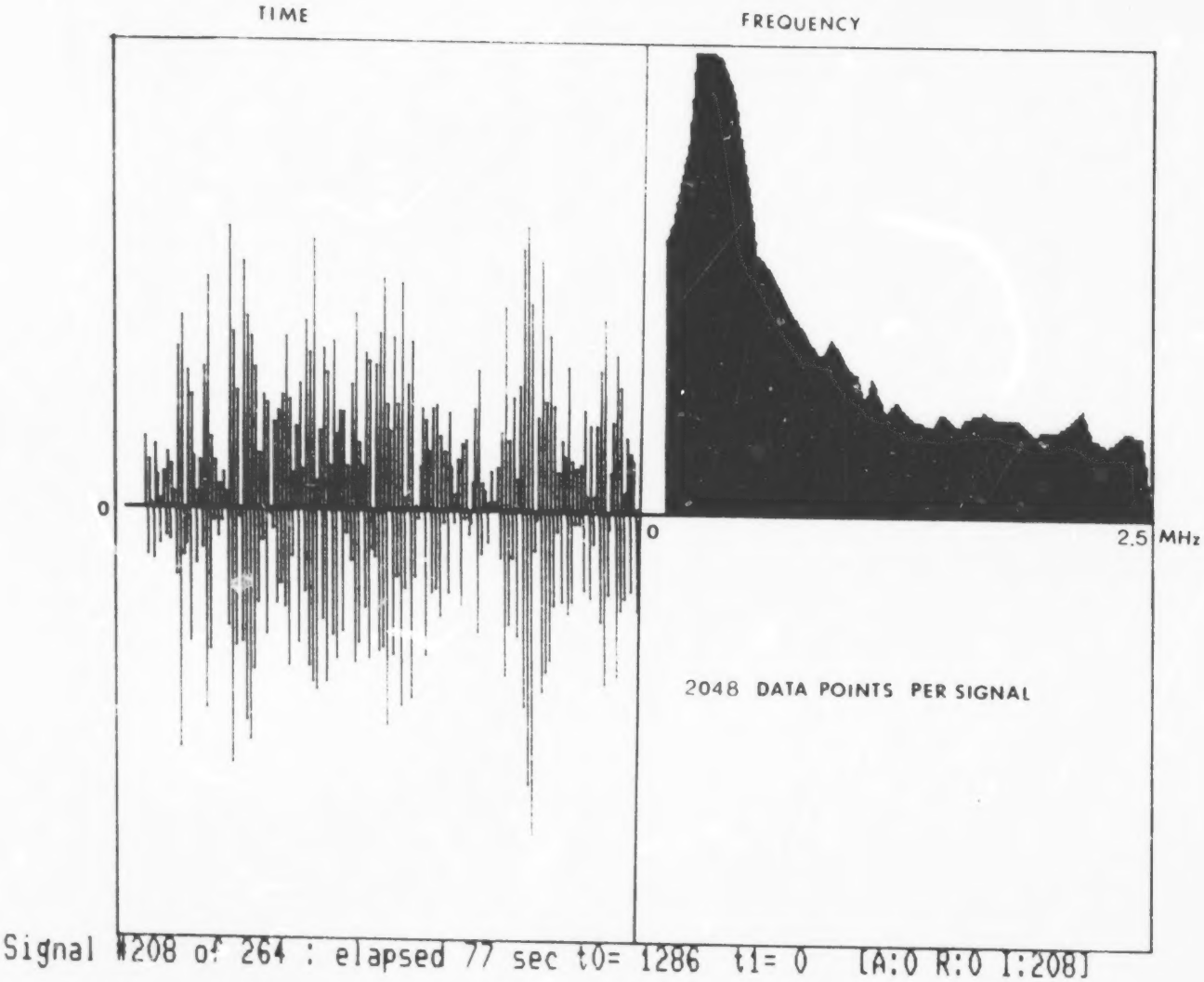

TIME
FREQUENCY
0
0
2.5 MHz
2048 DATA POINTS PER SIGNAL
Signal #100 of 264 : elapsed 38 sec t0= 0 t1= 1925 [A:0 R:0 I:100]_

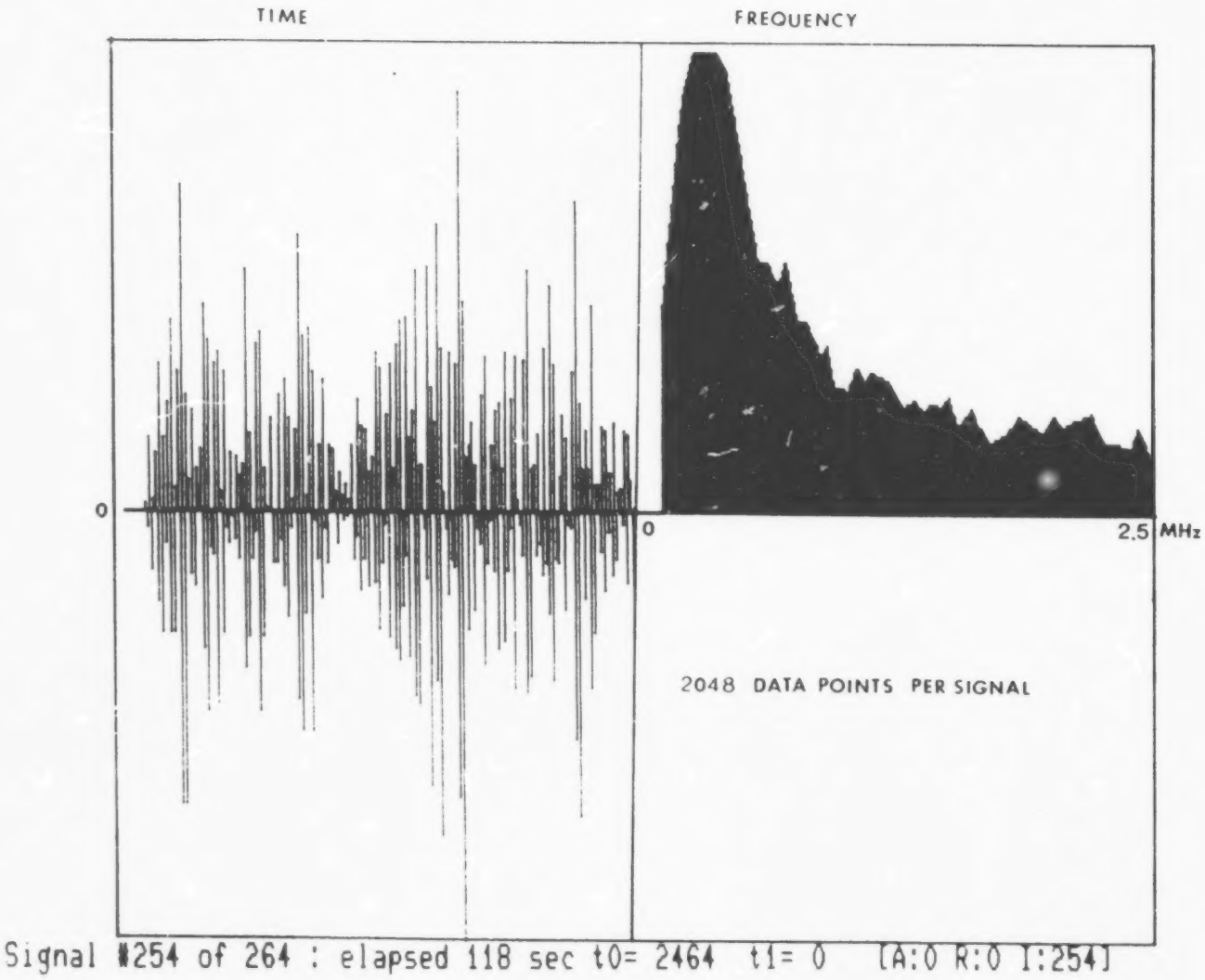

TIME
FREQUENCY
0
0
2.5 MHz
2048 DATA POINTS PER SIGNAL
Signal #101 of 264 : elapsed 38 sec t0= -8712 t1= 455 [A:0 R:0 I:101]

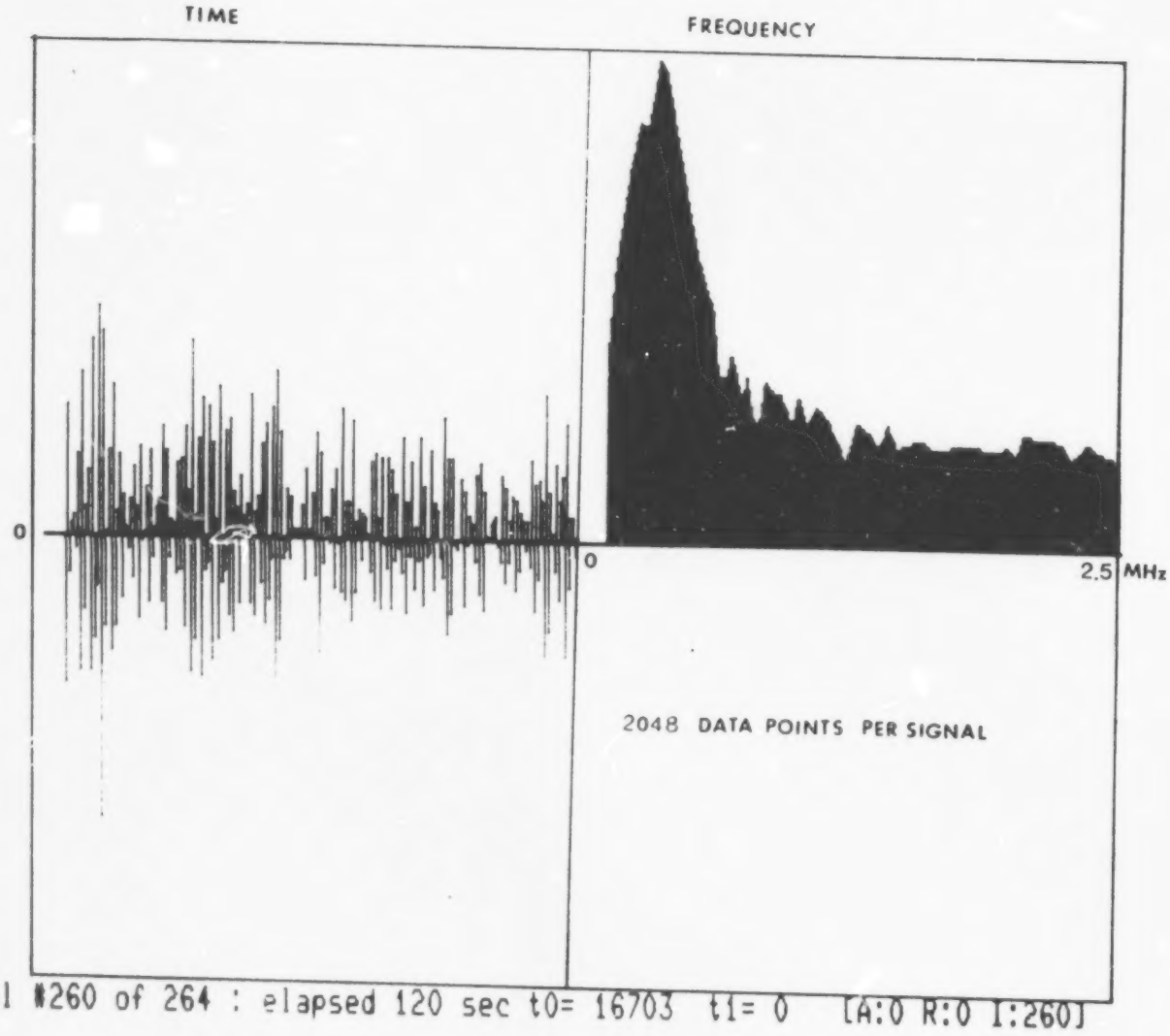

TIME
FREQUENCY
0
0
2.5 MHz
2048 DATA POINTS PER SIGNAL
Signal #127 of 264 : elapsed 49 sec t0= 0 t1= 221 [A:0 R:0 I:127]_



Signal #177 of 264 : elapsed 62 sec t0= 0 t1= 1692 [A:0 R:0 I:177]


TIME
FREQUENCY
0
0
2.5 MHz
2048 DATA POINTS PER SIGNAL
Signal #208 of 264 : elapsed 77 sec t0= 1286 t1= 0 [A:0 R:0 I:208]


TIME
FREQUENCY
0
0
2.5 MHz
2048 DATA POINTS PER SIGNAL
Signal #254 of 264 : elapsed 118 sec t0= 2464 t1= 0 [A:0 R:0 I:254]


TIME
FREQUENCY
0
0
2.5 MHz
2048 DATA POINTS PER SIGNAL
Signal #260 of 264 : elapsed 120 sec t0= 16703 t1= 0 [A:0 R:0 I:260]

POOR
QUALITY
ORIGINAL